Fraunhofer ISI

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ENERGY EFFICIENCY AND DEMAND FLEXIBILITY IN COMPANIES

Potentials, approaches and synergies to contribute to the energy transition

Fraunhofer-Institut für
System- und Innovationsforschung ISI

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Energy efficiency and demand flexibility in companies

Potentials, approaches and synergies to contribute to the energy transition

Energie-efficiëntie en vraagflexibiliteit in bedrijven

Potentiëlen, benaderingen en synergieën om bij te dragen aan de energietransitie

(met een samenvatting in het Nederlands)

Proefschrift

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Chapter I

Introduction

1 Introduction

The EU's (European Union) energy policies aim to establish a secure and affordable energy supply while meeting the requirements of sustainability and climate protection. To be in line with the Paris Agreement, the objective is to keep the global temperature increase below 2°C, respectively 1.5°C in the longer term. In the EU's strategic visions, e.g. the "policy framework for climate and energy in the period from 2020 to 2030" (European Commission, 2014) or more recently the EU 2050 long-term strategy (European Commission, 2018a), energy efficiency and an increased share of renewable energies are key elements of the decarbonisation strategy. These represent two of the five pillars of the EU Energy Union Strategy[1] (European Commission, 2019a). This has implications for the power system: On the one hand, improved energy efficiency is likely to reduce the demand for energy or at least avoid an increase. On the other hand, the share of renewable energies in the energy mix, especially volatile electricity sources (like wind and solar), now exceed 30% of gross electricity consumption in the EU today, with further rapid increase expected (Eurostat, 2018). If the load curve of demand stayed as it is, this would lead to strong fluctuations in electricity generation and pose new challenges for the security of supply and a stable grid operation (Stadler, 2005; Pfluger et al., 2017). To avoid this situation, it would be ideal if demand adapted flexibly to the amount of generation, and vice versa. Thus, the traditional principle of the power system, where generation typically followed demand, needs to be reconsidered. New strategies will be necessary to pave the way for renewable energies, and new market structures and market players will emerge. The Energy Union refers to the "Energy Efficiency First Paradigm" (European Climate Foundation, 2016) when dealing with the challenges posed by the energy transition. This explicitly includes both, energy efficiency (EE) and demand response (DR) or aims at a flexibilisation of demand in order to support the integration of volatile renewable energies into the electricity system.

This thesis analyses how companies can contribute to the energy transition by improving energy efficiency or by more flexible demand and focuses on the synergies between the two. Due to their large share in energy demand, companies play a highly relevant role. Germany was selected as an example to illustrate the findings and the role of policy making. Germany's ambition for its "Energiewende" also relies on renewable energy, energy efficiency and demand management. Given the shared vision among EU Member States of a renewable-based, sustainable energy system, many conclusions can be transferred to them and to other countries world-wide.

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1 The Energy Union Strategy was launched in 2005 with the aim to align energy and climate policy with the regard to make the use of energy more secure, sustainable and affordable. The other 3 pillars are: Security, solidarity and trust (diversify Europe's sources of energy and ensure energy security); a fully-integrated internal energy market; research and innovation in low-carbon and clean energy technologies

The following sections introduce the main research issues and concepts framing this thesis. The first section illustrates the framework of energy policy relevant for energy efficiency and demand response. The second section discusses the role of companies in contributing to the energy transition by applying energy-related concepts of energy efficiency and demand response, how they and how they relate to each other. The third section highlights relevant factors influencing their decision-making to implement energy-related measures. The last section of this chapter presents the scope and outline of the thesis, describing the research questions and the data and methods used to answer these questions.

1.1 Framework of energy policy in the EU and Germany

The energy policies of the EU point out the relevance of energy efficiency and the integration of renewable energies by declaring energy targets and agreeing on plans how to achieve them. The EU policies are translated to national targets and plans, sharing the same vision on a secure, affordable and sustainable energy supply.

Energy efficiency is a cost-effective way to reduce greenhouse gas emissions and energy consumption and therefore forms one of the main pillars of European energy and climate policy. Additionally, energy efficiency reduces reliance the on energy imports because it lowers the energy consumption based on (typically imported) fossil fuels. An energy efficiency objective defined in 2009 for the Member States is to reduce energy consumption by 20% by 2020 compared to baseline projections (European Commission, 2009a; 406/2009/EC). The target increased to 32.5% by 2030 in the revised Energy Efficiency Directive (EED) of 2018 (European Commission, 2018b, Directive 2018/2002) for primary and/ or final energy consumption compared to baseline projections. Article 7 of the EED establishes a common framework of measures to promote the Union's 20-20-20 target, remove barriers and overcome market failures.

Increasing electricity generation from renewable energy sources is another important means to reduce greenhouse gas emissions. The Directive 2009/28/EC (European Commission, 2009b, 2009/28/EC), encourages Member States to promote the use of energy from renewable sources and sets national targets consistent with a 20% share of energy from renewable sources by 2020. The revised Renewable Energy Directive in 2018 (European Commission, 2018c, Directive 2018/2001) updated the target for 2030 to 32%.

The National Energy and Climate Plans (NECP) improve the monitoring and coordination of the EU members' 2030 energy policy targets (European Commission, 2019b). The NECPs cover the five pillars of the Energy Union for the period 2021 to 2030 with a common reporting template. The current draft was due at the end of 2018 and a progress report is required on biennial basis. They consolidate the former NEEAPs and NREAPs (National Energy Efficiency/ Renewable Energy Action Plans, European Commission, 2012; 2009b) in

which Member States outline a road map and improvements to show how they intend to achieve their individual targets.

The German Federal Government translated the EU targets into national targets in its 'energy concept' (Bundesregierung, 2010, Energiekonzept), which features energy efficiency and increased renewable energy sources as its main pillars.

Like most EU Member States, Germany will probably not meet the energy efficiency target regarding the planned reduction in energy consumption for 2020 (European Commission, 2017). According to the report on the development of renewable energies for 2018 (BMWi, 2019), Germany has so far achieved a 9.8% reduction in primary energy consumption (compared to the aim of 20% by 2020) and a 3.9% reduction of gross electricity consumption (compared to the aim of 10% by 2020). To achieve the targets, the importance of proposed measures needs to be emphasized, cp. the NEEAP, Article 7 EED, or the NAPE published by the German government (BMWi, 2014), which contains strategies, immediate actions and sector-specific measures to improve energy efficiency.

Regarding the share of renewable energies, Germany will presumably achieve the target set for 2020. Germany reached a share of 16.7% renewable energies in gross final energy consumption and 37.8% of gross electricity consumption in 2018 (BMWi, 2019). The strongest growth was in wind and solar energies. The future challenges will no longer be just a matter of adding renewable energies as quickly as possible. A secure and stable energy supply also needs various processes to be interlinked, in particular the interaction of existing power plants, renewable energies, flexible demand and storage and consumption (UBA, 2018). The target share of renewable energies by 2050 thus is still a challenge, especially due to the intermittent nature of most renewable energies, their difficult predictability and factors that cannot be influenced, like the weather (Klobasa, 2013).

1.2 Energy efficiency and demand response in companies

In the light of the energy policies supporting the energy transition, energy-related measures influencing the demand pattern are means to achieve the targets. This section focuses on the concepts energy efficiency and demand flexibility, how they can be realised in companies and how these concepts relate.

In Germany, electricity use in the commerce, trade and services sector amounted to 151 TWh (equivalent to about 29% of total electricity demand), and accounted for 388 TWh (14%) of final energy demand in 2016. Industry accounted for 227 TWh of electricity use (44% of total electricity demand), and 722 TWh (29%) of final energy demand (AGEB, 2018). Therefore, larger potentials for energy-related measures (energy efficiency or demand flexibility) can be expected in the non-residential sectors and are the subject of the research in this thesis. Due to their high energy intensity, industrial companies are an

obvious target group, but the processes with the highest energy demand are usually part of the core business of companies here and are thus sensitive to changes in normal operation. In the service sector, a larger share of the energy consumed is for the operation of less critical cross-cutting appliances, which might be more suitable candidates for changed energy consumption. Compared to industrial companies, the energy consumption per company and thus the potential for energy-related measures is smaller and regionally more distributed.

1.2.1 Energy efficiency (EE)

"Efficiency" generally describes the ratio between used resources and achieved results or useful output, i.e. a maximization of productivity or utility (Linz, 2004). Energy efficiency (EE) is usually defined as the ratio of useful energy output to input (Patterson, 1996). Different aspects and perspectives of energy efficiency need to be distinguished in the interdisciplinary discussion (Irrek and Thomas, 2008). The use of the term energy efficiency is also related to wide-ranging topics like energy savings, changes in energy consumption, energy sufficiency and the energy transition. The concept is closely related to but distinct from "energy savings", i.e. a reduction in the use of energy (Directive 2012/27/EU, Art. 2(4) and 2(5), European Commission, 2012). This implies that if output is kept on the same level, energy savings result due to increased energy efficiency levels. For instance, the use of energy saving bulbs represents the energy-saving aspect of energy efficiency. The ratio "energy required per output" is also often referred to as "energy intensity", mainly when monetary output is the output measure (IEA 2014, p.17). Besides several relevant dimensions of energy efficiency (like a baseline, in- and output, the related timeframe and methodological aspects), system boundaries also need to be defined to evaluate energy efficiency (Schlomann et al., 2015b). In the given context, the changing energy system as well as the companies where energy-related measures can be implemented are different "systems" boundaries. Considering the integration of renewable energy sources, load management can result in a smaller number of power plants being required and thus lead to a more efficient use of energy at the level of the energy system.

Typical (cross-cutting) measures to improve energy efficiency in companies can usually be assigned to one of the following categories (cp. EEFIG, 2019; Rohde et al., 2015):

- Insulation/ building envelope
- Heating/ cooling/ refrigeration
- Ventilation/ air-conditioning
- Distribution of heat or cold or compressed air
- Process heat/ cold
- Lighting and sensors
- Motors and pumps
- Energy management/ -monitoring/ -measurement
- Change or improvement of energy systems or energy carrier
- Organisational measures (change of working or production processes)

In most cases, the measures change components, optimise the control or automation or introduce insulation to avoid energy losses. A number of studies have already revealed the considerable potentials of energy-efficiency measures (Blok, 2004; Worrell et al., 2009; Eichhammer, 2013; Fraunhofer ISI et al., 2014). Accordingly, increasing attention has be paid to improving energy efficiency in the energy policy of many countries (IEA, 2012). Energy efficiency is seen as an essential objective of the energy policy framework and is often called Europe's "first fuel" in 2030 (Saheb, Ossenbrink, 2015). Studies of energy efficiency and improving energy performance typically encounter the so-called "energy efficiency gap" (Jaffe and Stavins, 1994; Stern, 1992) which refers to the difference between the status quo and economically attractive energy-efficiency improvements. The reasons for this gap are diverse. In general, a number of internal and external barriers prevent the successful implementation of measures. The relevance of barriers varies with the target group and the measures need to match the characteristics of the company. An often neglected dimension of energy efficiency are non-energy benefits (also "multiple benefits") of measures that could function as drivers. These benefits include e.g. improvements in productivity, reduced maintenance or improved control and monitoring of appliances (cp. Nehler et al, 2016; Worrell et al, 2003). Improved control of appliances can also be advantageous when using the appliance flexibly for DR purposes.

1.2.2 Demand flexibility - demand response (DR)

As a consequence of the increasing share of volatile electricity in the energy system, the power grid faces challenges regarding system stability and the security of supply. Conventional power plants are currently used for load balancing to compensate fluctuations in the electricity load and supply as well as to counter grid congestion caused by geographically concentrated feed-in of renewable energies. By switching them on or off, these can compensate for discrepancies in electricity production and consumption or critical grid status (ETG, 2012). However, this approach stands in contradiction to the basic idea of the energy transition due to the ongoing demand for conventional power plants and runs counter to the climate targets set within this framework. This is especially true given the increasing need for control energy, which will make this option more costly in the future (Dena, 2016).

Regulating demand is one way to tackle current and future challenges like volatile energy supply, decentralized generation and critical energy grid situations. This is usually referred to using the term "Demand Side Management" (DSM), although such terms are not always used consistently. "Demand response" and "loadshift" are sometimes used synonymously. Other DSM definitions assume changes in the amount of energy used (cp. energy efficiency) or changes in the time of use (Palensky and Dietrich, 2011, Cowart et al., 2017; IEA, 2016) or use DSM measures as an umbrella term for related concepts like energy efficiency, time of use or energy balancing and thereby pool approaches for controlling energy demand. In this thesis, the term demand response (DR) is used to describe a specific mechanism to

utilize flexible demand with which individual consumers can contribute to DSM by changing their consumption pattern "behind the meter". The term demand response implies that changes in demand happen as a reaction to the status of the grid or energy availability. The term demand flexibility (or energy flexibility) refers to the attribute of a company's demand that is needed to participate in DR. This flexibility can be either market-driven (e.g. to use unforeseen renewable electricity generation) or grid-driven (e.g. congestion management). The goal of DR is not necessarily the reduction of energy consumption, but the avoidance of high power costs, costs for grid expansion or backup power plants and conventional energies due to demand following generation (instead of vice versa).

Besides participation in the balancing markets to trade flexible electricity, options to utilise flexible electricity demand include load shedding, optimized purchase of electricity, time variable electricity tariffs or other bilateral contracts with the grid operators.

While energy efficiency concepts and measures are already intensively examined in all sectors, flexibility options are predominantly applied in energy-intensive sectors for internal purpose of load shedding. Hence, it makes sense to expand the use of flexible demand to other consumers and sectors. Besides companies with high electricity demand, companies with power-consuming operations that are not part of the core business processes are suitable for DR. When estimating flexibility potentials, most studies define the duration during which a certain appliance can be switched off and how often the switching can be repeated (cp. Gils, 2014; Klobasa, 2007). Usually, ancillary cross-cutting appliances are suitable for automated DR, because they do not directly affect the core business processes. These appliances can usually be found in numerous companies across the service sector. The aggregated potential of the service sector could make a large contribution to stabilising the grid. Compared to the more local potentials of industry, the service sector's companies are spread across the country and their distributed loads could be used for local grid management in any region, e.g. at distribution grid level.

When referring to these cross-cutting flexible appliances that can be used for DR, mainly the compilations by Klobasa (2007), VDE (2012) and Gils (2014) are taken into account:

- Cooling and refrigeration (fridges, freezers, cooling rooms, refrigeration rooms)
- Ventilation and air-conditioning
- Electric boilers
- Heat pumps
- Night storage heaters

However, barriers towards flexibility measures do exist as they do for energy efficiency measures. Element Energy Limited (2012) conducted interviews to understand consumer's experiences with DR and found comparable barriers for DR as for energy efficiency. Thus, it is reasonable to assume that a "demand response gap" comparable to the "energy efficiency gap" exists. Additionally, DR is less established in companies and they have less experience with it, so it can also be assumed that the focus is on different barriers than for EE.

In the European Network Codes (European Commission, 2009c), the Energy Efficiency Directive (European Commission, 2012) and the Commission's Energy Union Communication (European Commission, 2015), DR is mentioned as an enabler of the integration of renewable energies and the security of supply. The aim is to make use of demand-side flexibility and to integrate market players, including consumers. Yet there are still discrepancies between policy plans and actual regulation and differences in developments between the EU countries (SEDC, 2017). In Germany, regulatory barriers, in particular, are hindering market growth and there is a lack of clarity concerning market roles and responsibilities, especially for load aggregation. Appliances used for DR in the balancing markets need to be pre-qualified and the requirements are hard to meet for small appliances of non-industrial sectors, although these could be aggregated. Additionally, the existing network fees incentivise rather flat consumption patterns, and indirectly penalising the provision of flexible demand. So far, as well as power plants, the regulatory conditions favour large industrial companies as participants in the balancing market. Further attempts to integrate potentials are in progress: Dena (2016) presented a roadmap with recommendations for actions to overcome these barriers, e.g. by developing the regulation for network charges, facilitating prequalification and opening the market to smaller loads. The BNetzA (2017) published a discussion paper about obstacles and approaches for a better use of flexibility, dealing with regulatory challenges e.g. difficulties of market access or contradictory incentive structures and possible conflicts between market and grid issues (grid congestion vs. integration of temporarily available electricity from renewable sources).

1.2.3 Relation between energy efficiency and demand flexibility

Energy efficiency and flexible demand cannot be separated completely, especially from an energy system perspective. Efficiency and flexibility are two aspects of the same goal in the energy transition, as both contribute to the aims of climate and energy policies. Both concepts are related to changes in demand patterns and it can be assumed that experiences and technological innovations with one aspect can raise awareness and reveal opportunities for the other and vice-versa. Thus, from a policy perspective, it makes sense to combine them when working with stakeholders. The Energy Union refers to the "Energy Efficiency First Paradigm", which explicitly includes both energy efficiency and demand response (European Climate Foundation, 2016). However, the two concepts follow different logics that partially counteract. Usually, energy efficiency is related to the amount of energy, i.e. using less energy, while maintaining output; demand response is related to the time of consumption and entails changed consumption patterns at certain points in time in reaction to different energy prices. This means, from an economic perspective, that the benefits of demand response measures are partially uncertain while energy efficiency improvements are longer-lasting and predictable.

In the specific case of appliance use, load shifting can cause less efficient operation of the appliance, resulting in increased consumption. On the other hand, energy efficiency can reduce the general demand level and thus also reduce the flexible demand. A summary of the possible interactions or trade-offs between efficiency and flexibility measures is given by Schlomann et al. (2015a). Ecofys (2016) provides insights into how efficiency and flexibility options interact on the level of industrial appliances. Sometimes, there is a trade-off between energy-efficient and cost-efficient measures. This is especially relevant as some appliances are of interest to both DR and EE (especially in the case of heating and cooling appliances). Beneficial interaction effects can occur as well: Technologies to manage and control these appliances could be useful in both cases – applying EE as well as DR measures.

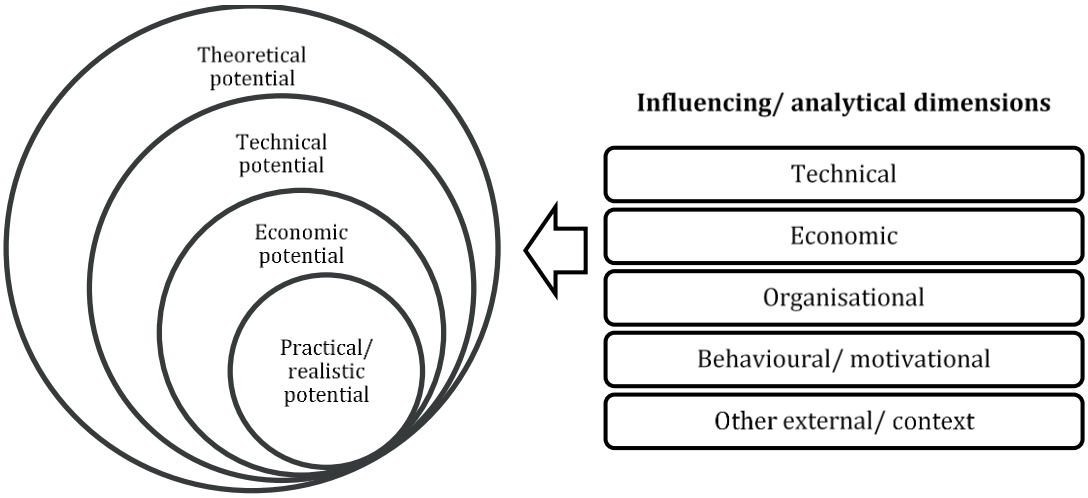
1.3 Factors influencing the potential of companies for energy-related measures

As mentioned above, a gap usually remains between the potential for energy-related measures improving energy efficiency or demand flexibility and the actual measures taken. The size of this gap depends on the criteria by which the potential is estimated, but also by internal and external factors influencing the decision-making on or the implementation of measures. This section discusses those factors that influence whether the potentials to take measures are tapped. The implications from these findings are presented in an integrated scheme that form the basis for the thesis' evaluation of factors influencing the decision-making to implement energy-related measures.

1.3.1 Different definitions of potentials

Different types of energy efficiency and demand flexibility potentials can be defined. Usually, theoretical, technical, economic and practical potentials are distinguished (Rudolph and Wagner, 1997). The difference in these potentials depends on whether technical, economic, organisational and behavioural/ motivational aspects are taken into account. While the theoretical potential can be seen as an upper limit, representing the maximum potential of all appliances eligible for measures, only a share of this can actually be realised due to technical, economic and practical restrictions that determine the related potential. Technical restrictions refer to the availability of appliances, their load profiles or usability of interfaces. Economic restrictions refer to the financial viability of measures, expenses or payback periods. The practical potential includes organisational barriers and the willingness of the persons in charge to implement measures. However, these barriers are not cast in stone and supporting policies could help companies to overcome them.

Figure I-1: Different definitions of potentials (cp. Rudolph and Wagner, 1997)



1.3.2 Barriers to energy efficiency and demand response

When potentials to optimize energy consumption are identified, they can only be tapped to the extent to which the companies are willing to take the appropriate measures. The drawback here is that energy is usually not a main focus in these companies, so implementing energy-related measures or investments is not a major priority. Thus, it can be expected that several barriers hinder the realisation of the potentials.

The taxonomy of barriers regarding energy efficiency is well researched and associated with internal procedures, routines in decision-making, organizational and financial options and external restrictions (cp. Sorrel et al., 2011). Recent research distinguishes economic, organizational, technological, behavioural and information-, competence- and awareness-related barriers to energy efficiency (Cagno et al., 2013) and more or less reflect the analytical dimensions mentioned above.

Table I-1: Simplified taxonomy of barriers (cp. Cagno et al., 2013)

Origin	Area	Exemplary barriers
External	Market situation	Energy prices, market risks
	Politics	Lack of proper regulation
	Technology/ service/ energy supplier	Suppliers not updated, characteristics not adequate
	Capital supplier	Difficulties in identifying quality of investments
Internal	Organisational	Effort too high/ lack of time, complex decision chains
	Behavioural	Lack of interest/ priority, inertia
	Economic	No capital availability, profitability unclear
	Competence and awareness	Missing information or awareness

The categorization varies slightly depending on the research focus. Some barriers often co-occur or are mutually dependent and the relevance of individual barriers varies depending on the stage of decision-making (Trianni et al., 2016). Usually, studies refer to self-reported barriers in order to evaluate the typical barriers that accompany certain measures in companies. It is often criticized that these reported barriers are not necessarily present, but might be a result of the biased perception of the person in charge (Trianni et al., 2013a). On the other hand, the person in charge makes decisions according to these perceived barriers and thus, in case of this stage of decision-making, his perception is more relevant than objectivity. Other studies argue that especially when decisions in companies also include investments, they can be well illustrated by just asking the persons in charge (Elliott et al., 1995).

The taxonomy has already been adapted for the drivers of energy efficiency (Trianni et al., 2013b), by assuming that many barriers are inverse to drivers, i.e. some drivers are considered the absence of barriers. Due to the relation between energy efficiency and demand flexibility (cp. section 1.2.3), it can be assumed that the nature of barriers also applies to other energy related concepts like demand flexibility.

1.3.3 The processes of decision-making on energy-related measures and innovations

Many aspects play a role in decision-making. In the field of energy research, there are several much quoted and applied theories that try to illustrate or predict the process of decision making and the adoption of energy-related measures or other innovations. Most of them describe decision-making as a process of evaluating alternative actions and their costs and benefits under the given circumstances. The evaluation usually results in an intention of action which ultimately may lead to an action or a change, i.e. the implementation of

measures. The conclusions from these theories form the basis for the thesis' concept of factors influencing the decision-making to implement energy-related measures.

From the perspective of a sociotechnical resp. technological innovation system, adopting those (energy-related) measures in companies might cause a change within the "system"[2] (i.e. in the company or the energy system). Changes involve uncertainty and dealing with new situations is rarely an uncontroversial, smooth process (Borrás and Edler, 2014). Thus, any change faces barriers related to the elements of the system (e.g. the company) and its characteristics (sector, size, routines, appliances and employees etc.) that can manifest themselves as e.g. technical, economic, organisational or behavioural impediments or blocking mechanisms (cp. the barriers mentioned above). The internal categories of barriers correspond to the four analytical dimensions in the theory of technical innovation systems (Jochem et al., 2009; Carlsson et al., 2002): the organisational/ institutional dimension, the societal/ behavioural dimension, the economic dimension and the cognitive technological dimension. The external categories are reflected in the relations to other system components, such as the market, policies, stakeholders, institutionalised structures and processes or technological capacities. The same dimensions can also comprise drivers or barriers that influence the willingness to implement measures and thus can also be an area of conflict in which decisions are made, as illustrated e.g. in the Technology-Organisation-Environment Model (TOE, DePietro et al., 1990). These barriers and drivers may originate from single components, but also from processes or the relations between them (Jacobsson and Bergek, 2011).

The evaluation of options is highly dependent on individual perceptions and attitudes and is not necessarily based on rational reasoning, but is a cognitive process. One reason is the bounded rationality of decision makers that prevents them finding the rationally most profitable option (Simon, 1972). If similar decisions are repeated, the best predictor of future behaviour is past behaviour, but if no experiences or habits exist, attitude plays a stronger role (Krueger et al., 2000; Ölander & Thøgersen, 1995). Attitude, norms and the perceived control over the outcomes (i.e. the opportunities and ability to perform the behaviour referred to the decision to take action) influences the intention to act (c.p. Theory of Planned Behaviour (TPB), Ajzen, 1985; Opportunity-Ability-Model (MOA), Ölander & Thøgersen, 1995). The TPB is one of the most cited behavioural theories and is frequently used to explain factors influencing energy-related behaviour, e.g. to predict environmental management practices in companies (Uhlaner et al., 2012; Sánchez-Medina et al., 2014) or renewable energy system adoption (Yun and Lee, 2015).

Describing the process or the phases of decision-making and especially the adoption of innovations, the theory of the Diffusion of Innovations (DOI, Rogers, 2003) describes phases of adoption from gaining knowledge to the confirmation of the decision. Different kinds of

2 A system is characterized by components with certain attributes and relations between components that interact and influence each other (Carlsson et al., 2002).

adopters (innovators, early adopters, early and late majority and laggards) can be distinguished by these phases that describe the shares of adopters of an innovation and its diffusion through a field of application over time. Recent energy-related studies use this theory, e.g. to understand the adoption of energy management systems (Sanguinetti et al., 2019) or renewable energy technology diffusion (Tabrizian, 2019), and combine this with other theories mentioned above, e.g. the Theory of Planned Behavior in the case of industrial energy conservation (Jacobsen and Guastello, 2007). The above mentioned DOI and the TPB (resp. the former Theory of Reasoned Action, Ajzen and Fishbein, 1975 – omitting the factor of perceived control) form the theoretical cornerstones in innovation and adoption literature (van Oorschot et al., 2018).

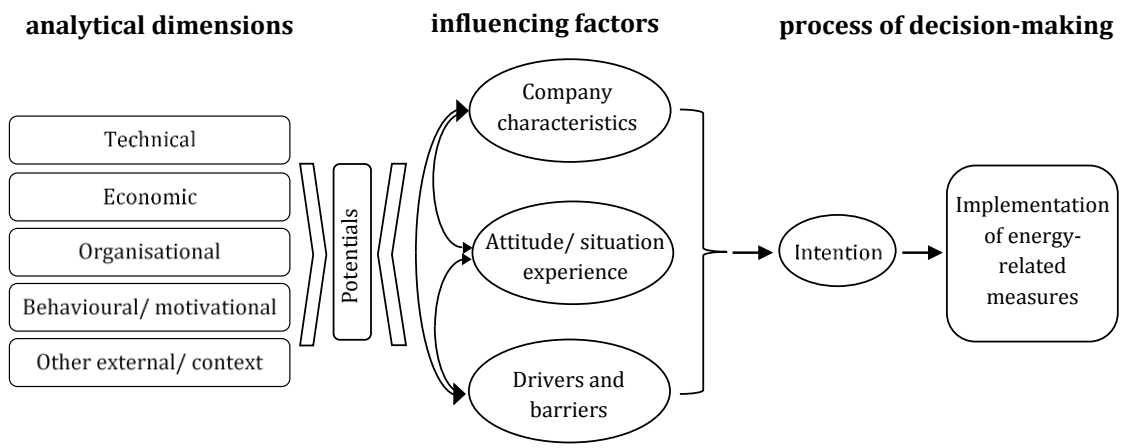
1.3.4 Integration of factors influencing decision-making and potentials

The following assumptions can be derived from these models and theories with regard to initiating the adoption of energy related measures in companies and are considered in this thesis:

- When implementing new technologies or measures, decisions often need to be made under uncertainty. Thus, the attitude and experiences of decision-makers and stakeholders play an important role.
- If the current standards in a company are changed by taking measures, the appearance of barriers can be expected. These barriers may be system-specific and depend on the company's characteristics or the measures in question. The relevance of the barriers can change during the process of decision-making or implementation.
- Measures can be implemented more easily if the measures are a good fit with the company, if relevant knowledge and decision-making routines exist and if the framework conditions are favourable. Some types of companies are more suitable and accessible to energy-related measures than others. Their characteristics need to be determined to identify suitable target groups.
- External and internal factors affect the potentials as well as the process of decision-making and implementation of energy-related measures, e.g. the market situation, policies, the novelty of the technology and the company's experience level, its economic situation and the availability of technologies or appliances. Each of these factors can support or impede implementation and are therefore possible points that influence the potential and decision-making. Organisational, technical, behavioural/ motivational, economic and context dimensions should be analysed to understand intentions and behaviour.
- The stated importance of energy issues and having the opportunity to implement measures does not necessarily lead to action. Nevertheless, the willingness or intention to do so is a strong predictor.

This thesis investigates the factors influencing decision-making regarding energy efficiency or demand flexibility and integrates the main factors from the above mentioned theories that are reflected in defined company characteristics (size, sector, availability of management systems, …), attitudes towards the concepts (e.g. regarding measures as a valuable contribution to the energy transition under the given circumstances) and the different internal and external categories of barriers or drivers. The characteristics of the influencing factors are shaped by the effects of especially technical, economic, organisational, behavioural/ motivational and external circumstances.

Figure I-2: Analytical dimensions and factors influencing the implementation of energy-related measures in companies



1.4 Scope and objectives of the thesis

Against the background of the energy transition, companies that improve their energy efficiency and flexibility of demand can contribute to achieving national energy targets. Regarding the challenges in achieving these targets and the future development of renewable energy sources, there are still knowledge gaps about how to fully tap energy efficiency potentials and demand flexibility potentials. Especially for demand flexibility, little research has been done that takes an integrated view of potentials, the external and internal factors affecting the willingness of companies to make use of potentials and how these potentials can be tapped practically. Therefore these aspects are the main themes of this thesis.

This thesis aims to contribute to bridging the knowledge gap by investigating the potentials and success factors of energy related measures in companies using an interdisciplinary approach and considering the analytical dimensions of organisational, technical, behavioural, economic and external factors. The identification of target groups, quantification of potentials and their determining factors as well as starting points for practical implementation are of major interest. While the drivers for and barriers to energy efficiency have already been deeply researched in detail, a comparable taxonomy regarding

demand flexibility has not yet been established and will therefore be issued in this thesis. When doing so, the knowledge and experiences gained by companies with energy efficiency measures are used to explore the applicability of the existing concepts and theories to demand flexibility. The concepts of energy efficiency and demand flexibility are interrelated, so possible synergies between the two are also addressed. Recommendations are made on how policy instruments could target both concepts together in order to enhance the effectiveness of the instruments supporting the energy transition.

Three main themes form the main pillars to address the research questions. They represent the "what/ who" (potentials and target groups for energy-related measures), the "why" (determinants and influencing factors of the potentials) and the "how" (how can potentials be tapped) of realising energy-related measures in companies and are equally relevant for energy efficiency and demand flexibility.

- **Identification of potentials:** approaches to find the most promising target groups or quantitative estimation of EE or DR potentials
- **The determinants and influencing factors of potentials:** drivers, barriers, framework conditions and other factors influencing the feasibility of implementing EE or DR, focusing especially on the main analytical dimensions: organisational, economic, behavioural/ motivational, technical and context aspects
- **Practical implementation:** Approaches and recommendations for how to best tap the potentials practically

When addressing these main themes, different analytical perspectives are taken:

- **technical**: aspects related to the appliances and technologies used in companies and their inherent restrictions on their use for energy-related measures
- **economic**: aspects associated with profitability or the financial affordability of energy-related measures or equipment
- **organisational**: these aspects include the institutionalised decision-making processes in companies, the availability of persons in charge for energy issues or sector-typical processes that affect potentials or the practical implementation of energy-related measures
- **behavioural/ motivational**: aspects related to the prioritisation of and interest in energy issues, the belief in ideas, the motivation of persons in charge
- **other external/ context**: e.g. market conditions, regulatory framework and the role of relevant stakeholders

1.4.1 Research questions and outline

The overarching research question for the thesis can be formulated as follows:

How can concepts of energy efficiency and demand flexibility be realised in companies?

Addressing this research question and tackling the main themes leads to the following sub-questions:

RQ 1 *How can energy efficiency measures be successfully implemented in companies and which determinants need to be considered?*

RQ 2 *Which companies are target groups for demand flexibility in the service sector and how big is their potential?*

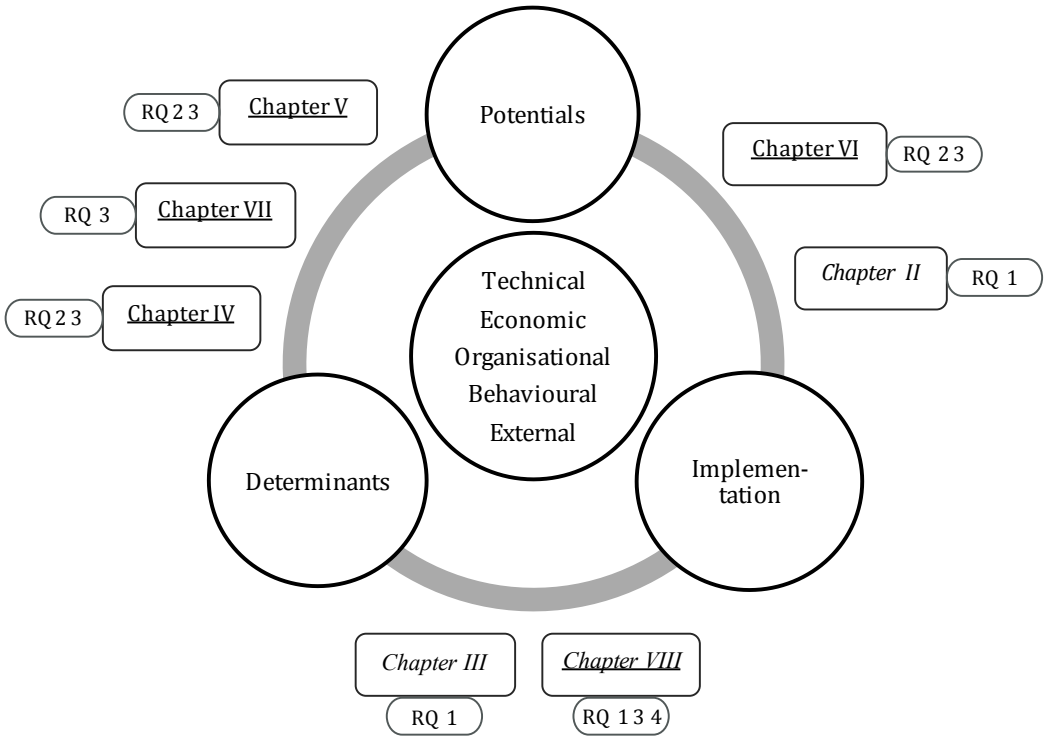
RQ 3 *Which determinants influence that flexibility potential in companies of the service sector?*

RQ 4 *How can we make use of synergies between demand flexibility and energy efficiency?*

The following figure illustrates the focus of the different chapters, showing the connection to the main themes, research questions and energy-related measures (efficiency or flexibility).

Figure I-3: Schematic representation of the structure of this thesis

How can concepts of *energy efficiency* and demand flexibility be realised in companies?



This thesis begins with the familiar concepts of energy efficiency and then addresses demand flexibility concepts which are novel to most of the companies. Industrial or manufacturing companies are - on average - more energy intensive than companies from the service sector. They should therefore be more motivated to improve energy efficiency and take different measures. The focus is first on barriers and drivers and then a deeper look is taken at success factors when implementing energy efficiency measures and how measures need to be tailored to match the specific companies' needs. The second focus concerning energy consumption in companies is on flexible demand options, which are less established compared to energy efficiency measures and with which companies are less familiar. In particular, sectors that have not yet been explored for their potential for demand flexibility measures, but that might become more important, i.e. the service sector, are investigated. Having determined the most promising target groups and estimated the flexibility potential, energy efficiency issues are compared to demand response topics in order to find out if the concepts are related and if earlier experiences with energy efficiency can be transferred to demand response strategies. Finally energy efficiency policies are considered and policy recommendations are provided to promote efficiency and flexibility options synergistically.

The investigation of the research questions is reflected in the choice of topics for the related publications each representing one chapter:

Chapter II: Learning networks as an enabler for informed decisions to target energy efficiency potentials in companies

This chapter investigates companies participating the "Learning Energy Efficiency Networks" (LEEN) and aiming to identify and implement energy efficiency measures. This setting is well suited to assess the relevance and influence of barriers, because the companies participated voluntarily and were keen to implement measures, so they had no reason to use barriers as a pretext. Additionally, keeping the companies informed during the networking process is a core element of the programme, so a misjudgement of difficulties due to missing information is unlikely. Analysing the monitoring data of more than 350 companies allows to evaluate the expectations, drivers and barriers that the companies face in the course of the programme and how information, cooperation and experiences can influence the success of implementing measures and alter the impact of perceived barriers.

Chapter III: Tailoring energy efficiency measures to target groups – approaches regarding cross-sectional technologies and barriers in industry

The research on RQ 1 revealed that a closer look at companies' characteristics is necessary to understand the specific needs in order to facilitate the identification and implementation of suitable measures. Hence, the LEEN data from Energy Efficiency Networks is analysed to find out how barriers to energy efficiency are related to specific types of companies and whether the potential to implement measures depends on company characteristics. The results reveal the main categories of barriers and their relevance in relation to companies' characteristics like size, sector and mechanisms of decision-making. Knowing more about the specific challenges and potentials of company types opens up the possibility to better tailor the measures and services aiming to improve energy efficiency and increases the probability that measures are actually implemented. It is also evaluated if specific measures are a better fit for specific types of companies and how policies can be improved to support implementation.

Chapter IV: Setting course for demand response in the service sector

The share of renewable energies in the energy system is increasing, but the market for demand flexibilisation is still underdeveloped and impedes the contribution electricity customers could make to the integration of volatile renewable power. So far, companies do not participate in DR in Germany, apart from a few energy-intensive industrial ones and their potential remains unexploited. The focus is to find promising target groups to activate their DR potential by applying a multi-method approach consisting of statistical data analysis, stakeholder interviews and

an evaluation of the current regulatory conditions. The aim of this chapter is to identify promising subsectors with DR potential that is relatively easy to activate, and to provide recommendations for the integration of further market participants. The identified target groups form the starting point for a deeper analysis within a broad survey of the companies of interest.

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

This chapter provides a comprehensive analysis of the DR potential of three of the most promising subsectors identified in the previous study – retail, offices and hospitality. The analysis of a large dataset from over 1500 companies gives deeper insights into the company characteristics associated with a high willingness to participate in DR and with high DR potentials. This study complements the previous Chapter by taking the perspective of a large number of companies into account. Three kinds of potentials are distinguished: the theoretically available flexibility potential, the technical potential and the practical potential determined by the electricity consumption of the flexible appliances, the technical restrictions of the appliances and the willingness of the companies to participate in DR. This part of the thesis aims to provide an overview of what has been done so far regarding DR measures in this sector and to quantify the potentials. The evaluation of drivers and barriers and their influence on participation in DR enables us to identify target groups and appliances suitable for DR. The results demonstrate the value and possible benefits of DR in companies and how measures can be incentivized.

Chapter VI: The flexibility deployment of the service sector – a demand response modelling approach with evidence from a market research study

Using the broad survey data, the analysis of flexibility potentials is expanded with a modelling approach. The model optimises the scheduling of flexible loads with the objective of smoothing the residual load. This approach is comparable to real-time-pricing that depends on the residual load curve, using the electricity consumption patterns of the appliances. It also allows us to take further technical and framework restrictions into account, e.g. generation profiles from renewable energies, weather data and projected structural changes. In contrast to Chapter V which assessed the available flexibility potentials, now the perspective of required flexibility and focus on deployable flexibility is taken, differentiating again between technical and practical flexibility deployment. In addition to the flexible energy used for load shedding, the contribution to the integration of renewable energies is shown. The results indicate whether the available potentials can be deployed, which appliances or subsectors can contribute the most and when demand flexibility is most needed. The insights gained can be used to estimate how future developments influence the potentials and options to integrate renewable energies and provide a rough estimate of the deployable flexibility potentials to serve this purpose.

Chapter VII: How much load flexibility can a euro buy? Findings from a choice experiment with companies in the German commerce and service sector.

The survey of companies evaluated the willingness to participate in DR options and how this can be influenced. Companies expect a monetary payback for providing demand flexibility. Therefore, a dichotomous choice contingent valuation "choice experiment" is used to estimate the monetary incentive required, i.e. the participants were presented with a scenario in which they could provide flexibility for a certain payback and decide whether to accept this offer or not. The evaluation reveals whether factors such as the duration and frequency of flexible use, company type and appliances of interest affect payback expectations. The aim is to discover whether some potentials are easier to tap and how the practical scenario needs to be designed in order to use the demand flexibility of companies in the economically most favourable way.

Chapter VIII: Energy efficiency and demand response – two sides of the same coin?

Energy efficiency and demand response are two main pillars of the energy transition. From the perspective of companies, these two concepts are related because they both aim at influencing energy consumption, but their practical implementation is associated with different challenges. The survey contains data on both energy efficiency and demand flexibility and is suitable for an evaluation and direct comparison of both aspects. By comparing earlier experiences with energy efficiency and flexibility and the drivers and barriers associated with measures, an overview of possible commonalities and differences is given. The aim is to build on the well documented experiences and findings regarding energy efficiency measures and to transfer them to novel demand response issues. An overview of existing energy efficiency policies is used to illustrate the options to promote energy efficiency and flexibility in companies synergistically. Recommendations are derieved on how existing activities related to energy efficiency can be used directly to foster of demand response measures.

1.4.2 Data and methods

The data relies on German projects that deal with questions of energy consumption and/ or its flexibility in companies:

- The LEEN-project (Learning Energy Efficiency Networks), where participating companies aim to share experiences and knowledge to implement energy efficiency measures. The Networks are supported by energy experts providing information on efficiency measures and implementation. A continuous assessment of evaluation data allows analyses of the programme's achievements of the program as well as of success factors or impediments. At present, there is information from around 400 companies in 30 pilot networks. The German government is in the process of extending these networks to several thousand companies.

- The study on the energy consumption of the tertiary sector, a biannual representative monitoring study that collects data on the use of energy in the trade, commerce and services sector from at least 2000 companies in Germany. This study focuses on energy use data and company characteristics that allow the estimation of energy consumption at the level of appliances in the subsectors. The survey also includes energy efficiency and load management aspects.

- The EnSys-FlexA and AVERS projects deal with demand flexibility options and collect data via stakeholder interviews and a survey of more than 1500 companies. The guideline-based interviews with several relevant players from the energy market are a multi-perspective investigation of the status quo, load management potentials and the barriers to their realisation in companies. Furthermore, the survey of companies focuses on DR potentials, technical conditions and attitudes towards implementing DR as well as expectations and experiences of energy-related measures.

The analyses are based on an approach using different qualitative and quantitative methods. The qualitative approaches included literature research and semi-standardised interviews. The interviews were conducted with the main stakeholders from a field of research and aim to gain insights into individual perspectives of developing areas, like future demand flexibility options. The interview data can be categorized into findings for the different topics and together provide a coherent view of the situation. Such data complement quantitative data and focus on describing, subjectively interpreting and understanding behaviour and contexts, e.g. to identify research gaps or to better understand what the numbers derived from quantitative approaches mean.
The quantitative methods include surveys and other, empirically assessed data or data from official statistics. Quantitative analyses comprise mathematical approaches such as descriptive and inferential statistical methods or modelling tools. The main methods used are:

- Regression analyses – to identify and quantitatively describe the relation between a dependent variable and one or more independent variables, e.g. to evaluate and predict the relevance of influencing factors on a target variable like the intention to implement energy-related measures.
- Factor analyses (principal component analyses) – to identify structures in the data and to combine correlating variables e.g. to reduce the set of influencing aspects or barriers to decision-making to the main factors.
- Significance tests - there are different procedures here. They all aim to distinguish between random and significant differences between investigated groups (e.g. company types) in order to judge the validity or invalidity of a hypothesis. For this purpose, variances of parameters within a type or group usually are compared to the variance between the groups.
- Other arithmetic or modelling approaches – specific to the calculation of the potentials. In this case, these are either step-by-step calculations of sums of consumption data, technical parameters and other influencing factors or calculations using a modelling approach based on optimising flexible loads to smooth the residual load and integrating additional parameters like load profiles and weather data.
- Contingent valuation choice experiments – used to estimate how much companies expect to be paid for providing flexible electricity. The companies are presented with a scenario in which they are paid a certain monetary incentive for their flexibility of demand. Their payment expectation are determined based on whether they accept or reject this proposal.

Detailed methodological descriptions can be found in the relevant chapters, where the methods are applied to a specific context and research question. The following table summarises the main topics, methods and focus of the chapters.

Table I-2: Overview of chapters, research questions, main themes, focus and methods

		Chapter						
		II	**III**	**IV**	**V**	**VI**	**VII**	**VIII**
Research question	RQ 1	x	x					x
	RQ 2			x	x	x		
	RQ 3			x	x	x	x	x
	RQ 4							x
Main themes	Potentials	x		x	x	x	x	
	Determinants/ influencing factors		x	x	x		x	x
	Implementation	x	x			x		x
Target sector	Industry	x	x					
	Service sector			x	x	x	x	x
Energy measures	Energy efficiency (EE)	x	x					x
	Demand flexibility (DR)			x	x	x	x	x
Approaches/ analyses	Methods	pre-post evaluation	factor analysis, significance tests, regression analyses	qualitative stakeholder analysis	math. approach, regression analyses	modelling approach	choice-experiment/ contingent valuation	policy analysis, comp. factor analysis, regression

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Chapter II

Learning networks as an enabler for informed decisions to target energy-efficiency potentials in companies

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Abstract

This paper deals with possibilities of targeting energy efficiency potentials in German companies by delivering information and support within a cooperative management system "Learning Energy Efficiency Networks" (LEEN). Information deficits are pointed out as a relevant barrier to implementing energy efficiency measures in literature that can be aimed at by energy programmes such as audits. Our concept combines aspects of cooperation, shared experiences and moderated learning processes. The programme sought to go beyond the sole provision of consultation, by qualifying companies to decide and act on implementing energy efficiency measures by delivering the individual practical know-how they need.

After having analysed evaluation data of several hundred companies, our results show that the participants were mainly motivated by the need for practical knowledge and specific information. The networks could well satisfy this need. The benefit for the participants in such delivered information was also reflected in the decreasing of the barrier of imperfect information and the programme enabled companies to make informed decisions on energy efficiency measures. But the gain of the programme was not solely restricted on an increase in knowledge: The majority of participants reported implementation of suggested measures, which would not have been implemented without the programme. Hence, LEEN can be indicated as a policy instrument enabling informed decisions on efficiency measures and supporting their implementation. Possibly tailoring the programme to different target groups and aiming at dismantling other barriers directly in addition to tackling information deficits could be undertaken to improve the process.

1 Introduction and background

Increased concentrations of carbon dioxides and other greenhouse gases (GHG) in our atmosphere cause the occurrence of climatological changes (Thomas et al., 2004). Under the Kyoto Protocol, the European Union was committed to reducing GHG emissions by eight per cent from 1990 levels by 2012 (Vatalis et al., 2012). The threat of those changes directed the attention of researchers and policy makers to the issue of sustainability resp. low carbon transition (Markard et al., 2012). Low carbon pathways will require fundamental changes in economies. Heading towards such a more sustainable energy system, a more efficient use of energy is seen as a cost-effective possibility to mitigate climate change and to contribute to enhancing supply security. But the changes cannot be reduced to technological innovations or policies – the whys, whats and the hows of expedient transformations have to be understood to upscale effects of promising practical measures.

Taking companies into the focus, a considerable potential can be expected, as industry still presents a share of about 28% in final energy consumption in Germany (UBA, 2014) and a little less with about 26% at the level of the European Union (odyssee-mure.eu, 2014). In emerging countries the share of industry is frequently the highest among all end-use sectors, for example in China it is about 51%, in India 34% (ENERDATA, 2014). Usually, remarkable cost-saving potentials can be identified for many energy-efficiency measures, as engineering-economic studies reveal (Blok, 2004; Grenade et al., 2009; Worrell et al., 2009; Fraunhofer ISI et al., 2014; Ecofys and Fraunhofer ISI, 2010; Eichhammer, 2013). But obviously those potentials are by far not fully exhausted by companies despite the supposed high economic pressure to realize cost reduction and profitability of possible measures (IEA, 2012a). The difference between the cost-efficient energy saving potential and the actual adoption of corresponding measures has been named the "energy efficiency gap" (Jaffe and Stavins, 1994; Stern, 1992) and investigated by many researchers since then (for example Sorrell et al., 2004; Backlund et al., 2012). Thus, the existence of various barriers and uncertainties prevents companies from realizing those theoretical opportunities (Worrell et al., 2009). In recent years, unused promotional factors have been identified as an additional aspect (Jochem et al. 2014). Nehler and Rasmussen (2015) investigated the role of non-energy benefits that should also be taken into account when decisions on energy-efficiency investments are made. Besides the problem, that those benefits can often hardly be monetised, many firms lack knowledge of those additional gains. Additionally, those effects interact in complex ways and appear on different levels (IEA, 2012b).

Different typologies and reviews of barriers exist (e.g. Jaffe and Stavins, 1994; Hirst and Brown, 1990; Brown, 2001; Sathaye et al., 2001; Sorrell et al., 2004 and 2011; or Cagno et al., 2013, Trianni et al., 2013a). One barrier of general importance for the process of decision-making is prevalent in literature (Gruber & Brand, 1992; Thollander et al., 2007; Schleich & Gruber, 2008; Schleich 2009; Schröter, 2009; Trianni and Cagno, 2012; Cagno and Trianni, 2014) and its elimination seems more like a precondition for the decision to undertake a measure than a reason: lack of information.

Compared to the restructuring of financial allocation, technological conditions or internal organizational barriers, the supply with information is less invasive and can be delivered without obligation, which might make this barrier comparatively easy to reduce. Some studies have even highlighted a greater need to focus on information barriers than on economic issues (Trianni et al., 2013a; SPRU, 2000); above all, it is necessary for companies to make an informed decision anyway. This means that information might be a key to lower the threshold to comply with energy efficiency measures.

To overcome the barrier of imperfect information, Hirst and Brown (1990) suggest government-funded industrial energy programmes to increase energy efficiency in industry, but point out that information programmes might be appropriate for tackling many of the barriers discussed above as well. They also highlight that the absence of such information leads to greater perceived risks and might impede the adoption of efficiency measures.

Other studies have already investigated concrete instruments targeting the information barrier. General information campaigns usually induce higher awareness of energy efficiency, but they rarely end up by adopting efficiency measures, while local energy programmes containing company-specific information, ideally presented by trustworthy facilitators, are more successful in increasing the adoption of energy efficiency measures (Stern and Aronsson, 1984).

The Australian EEAP (Commonwealth Government's Enterprise Energy Audit Programme) was a large-scale energy efficiency programme between 1991 and 1997, which offered energy audits at a 50% discount. Over 1000 firms, with an average of about 300 employees, participated and achieved an adoption rate of about 82% for the suggested measures (about six recommended measures per firm, Harris et al., 2000). Another large energy programme for industry in the USA was the American Information Assessment Center's (IAC) programme, which offered energy audits for SMEs. Over 10,000 manufacturing firms participated and more than half of the recommended measures were implemented. Those measures which were not implemented were usually neglected for economic reasons (Anderson and Newell, 2004). This reason is in itself an obstacle, given the findings of Schröder et al. (2009) that 85% of companies base their decisions on energy efficiency investments with short term payback periods and do not consider profitability criteria. Fleiter et al. (2012) came to comparable results, analysing energy-efficiency measures in SMEs, that high investment costs still impede the adoption even for profitable measures. Considering that non-energy benefits are often overseen while deciding on energy-efficiency investments, Nehler and Rasmussen (2015) found profitability and payoff crucial criteria for adopting investments, too. Thollander et al. (2007) evaluated the Highland programme in Sweden funded partly by the European Union's programme *Objective 2 South Sweden*. This local energy programme included 340 energy audits in six municipalities, of which 139 audits were made in manufacturing companies and an adoption rate of about 40% for suggested measures was achieved. The evaluation indicates that the involvement of intermediates (e.g. local energy agencies or energy consultants) contributes to the

effectiveness of such programmes but states that further work in order to improve the energy auditing procedure is suggested as an area for future research.

Our study aims at enriching the empirical basis of information barriers to energy efficiency in companies by making use of recent evaluation results of a new policy instrument introduced in Germany as a large pilot project between 2009 and 2014. This instrument are the "Learning Energy Efficiency Networks" (LEEN). These networks are one of the immediate actions within German Government's National Action Plan on Energy Efficiency (NAPE; BMWi, 2014). Therefore the success of this instrument in terms of overcoming informational barriers and thus initiating concrete energy efficiency measures in companies is also of high importance for the success of a new German energy efficiency strategy with regard to the industrial sector. Other instruments within the immediate actions for this target group have other focuses, like financial support or solely informational character (audits). Amongst the immediate actions, the networks are one of those with the highest expected savings. Around 75 PJ of energy savings per year are expected by the extension to 500 planned energy efficiency networks in 2020 (about 3% of total industrial energy use in Germany) and avoided CO_2 emissions of around 5 million tonnes (BMWi, 2014). The outcome of the networks running so far in Germany is that energy efficiency progress has doubled compared to the autonomous progress (that is, progress that occurs on average for non-participants; klimaschutz.de, 2014). The transaction costs for the companies to undertake energy efficiency measures are lowered (Mai et al. 2014). This new policy instrument was originally developed in Switzerland in the late 1980s (Bürki 1999; 1999; Kristof, 1999) and is now widely applied in Switzerland due to the possibility that companies can avoid the payment of the CO_2-surcharge (presently 60 € per tonne of CO_2), if they join an energy efficiency network (EnAW 2014).

2 Focus and hypotheses

The idea of the networks is to target the idle potential for energy efficiency in medium-sized and large companies by cooperation on a regional level, focusing on the companies' own interest rather than framework settings and regulations. Target agreements for energy savings as well as individual energy audits with direct involvement of companies concerning the collection of appropriate measures are part of the concept. However, the participants moreover benefit from systematic information, a quarterly exchange of experiences, site visits, and yearly monitoring over several years as well as the support of a network manager, a moderator and a consultant engineer who bring technological knowledge to the networks. Apparently, the LEEN are far more than an "audit programme". Thus, one aim of the LEEN was to enable the participating companies to learn about given possibilities by exchanging of their experiences to make informed decisions and profit from synergies to make the implementation of energy-efficiency measures possible.

Additionally, the data collected during the network-phase, including surveys, allow a systematic investigation of the role of information, of the needs of participating companies, their effect on the barrier of lacking or imperfect information and the decision making routines concerning efficiency measures.

The hypotheses to be investigated in this paper are:

(1) first that the participants' expectancies and needs can be met so that those informative voluntary networks can reduce barriers affecting the implementation of energy efficiency measures, especially information deficits;
(2) second that the networks can overcome these informational barriers (besides others) and trigger companies to actually implement energy efficiency measures.

The methods we use to analyse the role of information in the decision making and routines of the companies are a factor analysis of the companies' expectations before entering the networks to clarify the dimensions of their motivation and t-tests to identify changes between the beginning and the end of the network phase, concerning experiences and their perception of barriers.

The paper is organized as follows: In section 3 we provide a description of the basic evaluation study together with descriptive statistics and the methodological approach used in the analyses. The analyses results are presented in section 4. In section 5, we interpret and discuss these results. In the concluding section 6 we derive some implications for further research and development of efficiency instruments.

3 Methods and Data

3.1 Database – the LEEN

The recruiting of companies for the LEEN is done by the network operators (e.g. utilities, industrial associations and platforms, Chambers of Commerce and Industry, city governments, or consulting engineers) by information events or personal acquisition. They often draw on existing structures like environmental working groups, which offer easier access to potential participants or membership and sales structures of utilities or banks. There are presently two types of networks (1) for medium sized and large companies with yearly energy cost between 0.5 and 50 million €/a and (2) for small and medium sized companies with yearly energy costs between 30.000 and 500.000 €/a. This structure ensures that participation is profitable for the participating companies.

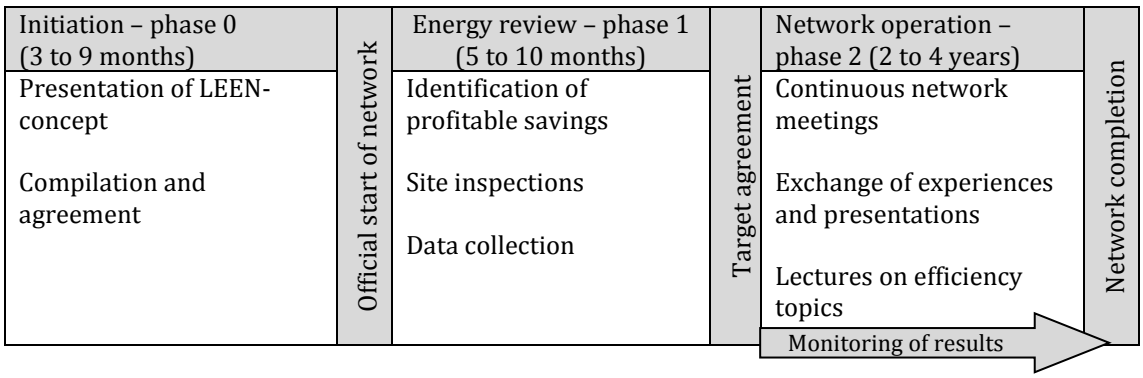
The focus of the energy audit and the information and exchange of experience is on a set of common cross-cutting technologies (technologies which are not limited to special industries, but applied across different sectors such as heat generation, electric motors and their applications in pumps, ventilation, compressed air or cooling systems, heat recovery

etc.) but also on organizational measures such as staff motivation, involvement of the energy manager in the tender process for new production machines etc. In order to secure an open exchange of ideas, plans and experiences the companies participating in the network should not be in competition with the same customer.

After an information event (phase 0), a consultant engineer analyses existing saving potentials by conducting an energy audit on the sites of the participating companies (phase1, see Figure II-1). The companies fill in a data form concerning their energy situation and the certified consultant engineer carries out the energy audit by means of a set of available electronic tools. On that basis the participants decide individually on an efficiency target (confidential) and commit themselves to a voluntary energy saving target of the network and regular exchange of experiences in groups of 10 – 15 companies for at least the next 3 – 4 years (phase 2).

A LEEN-certified moderator plans and conducts the meetings. All network participants report on planned or implemented measures so that the other participants can benefit from their experiences. This information exchange, which allows an exchange of experiences as well as mutual confirmation and appreciation, the site visits during the meetings, and the possibility to utilize synergies in the networks are central success factors for the concept (Köwener et al., 2014). This exchange is especially valuable as the provided information is presented by a colleague and not a sales representative or consultant (Köwener et al., 2011). Additionally, the peer pressure concerning the common network target promotes progress towards the common goal (Jochem et al., 2007). These social-psychological effects facilitate the diffusion of energy-efficiency innovations as an informal competition in achieving energy efficiency progress among the companies and the energy managers can be observed (Jochem et al., 2012).

Figure II-1: Procedure of the LEEN (illustration based on Rohde et al., 2015)



The companies pay a fee, which is used to finance the energy audit, the regular network meetings and the yearly monitoring, which accounts for up to 2/3 of the network costs (approximately €35,000 to €40,000 for a typical participant with annual energy costs of about €1 million to €2 million and four-year network operating period, Köwener et al., 2011). The success is measured through the annual monitoring and documented by the consultant engineer. Those results are fed back to the companies' management. Participation in the LEEN can also be used as preparation for the implementation of energy management systems, as some requirements of DIN 16001 or (today) ISO 50001 are met (Di Nucci, 2012).

The quantitative monitoring performed jointly by the energy manager and the consulting engineer came to the following conclusions and cover all results: the annual average efficiency improvement of all 366 companies was 2.1% (Jochem, 2010; Köwener, 2014). In comparison to the average energy efficiency progress attained by German industry as a whole, autonomous energy efficiency increases by approximately 1% per year (Di Nucci, 2012; Schlomann et al., 2014). In absolute terms this resulted in energy savings of about 5 PJ/a after 4 years of the duration of the 30 networks (in monetary terms: 72 million € energy cost savings per year). The investments involved were less than 200 million € over four years (Jochem, Idrissova, 2014). Moreover, when 100 efficiency measures were realized in the networks, about 60 new ideas for further efficiency measures were generated as a result of the increasing knowledge and competence of the participating companies and due to technical innovation reaching profitability. Furthermore, energy managers' knowledge enhanced due to the course of the intensive engagement within meetings and exchange of experiences; it even led to suggestions and concise demands for improving the energy efficiency of machinery and plants of machine and plant manufacturers (Jochem et al., 2014).

The programme of the 30 pilot networks was funded between November 2008 and March 2014. The funding covered the cost of further developing of the LEEN management system, including 17 investment calculation tools for crosscutting technologies, the evaluation of the performance of the 30 networks with its 366 companies as well as public relations to report the successes to a broader audience of the German industry.

3.2 Methods

Our analyses rely on data from two of three sequential surveys, which were conducted within the longitudinal evaluation process of the programme and were filled in by a company representative who is familiar with energy issues. Questions on expectations on the coming process as well as the evaluation of specific elements, questions on companies' characteristics and structure and also attitudes and estimations of possible barriers towards energy efficiency were part of the inquiry. In this study we focus on issues within the first and the last survey, comparing the differences that occurred in the participants' reports as well as an assessment of the knowledgability and expectations the participants

entered into the programme on the one hand, and the experience and reported efforts within the programme on the other hand. In detail, those topics are:

- Data concerning the company: independence of company (binary), estimated intensity of energy use (5-point scale), experience with comparable networks (binary)
- Rating (5-point scale) of expectancies (beginning)
- Rating (5-point scale) of fulfilment of expectancies (end of programme)
- Rating (5-point scale) of perceived barriers at the beginning and the end of the network phase

The first survey was carried out at the initial network-phase, mostly in the beginning of 2011, depending on when the network was ready to start. The last survey was conducted in the second half of 2013 for most of the companies.

In the following, we refer to those participants that filled in the first survey. For comparisons between the first survey and the one at the end, we limit the data to those participants, who completed both surveys. Analyses which refer only to data of the last survey were conducted with all participants' data available for that survey.

Our statistical analysis employs survey data relying on 366 companies (of the 30 networks) from the longitudinal evaluation of the networks. The number of companies that responded in the second survey was thus lower than in the first survey (301 vs. 213 respondents of 366 participants in total). An analysis of the companies' businesses revealed that the participants are predominantly medium-sized and large firms from the manufacturing sector (75%, referred to respondents of the first survey), other groups (e.g. hospitals, large public and commercial buildings) of represented sectors are distinctly smaller. Their yearly energy costs range between 0.4 million and 50 million €. Very energy-intensive companies with energy cost shares of total production costs above 12% did not participate. The companies perceived their own energy consumption as "rather high" (rating of 3.7 on a scale from 1 to 5). Their energy intensity varies between the companies; regarding companies from the manufacturing sector, representatives with energy intense processes (like manufacturing of pulp and paper or chemical products) as well as lesser energy intense processes (like manufacturing of leather products or wearing apparel) are part of the sample.

Descriptive analysis is used to depict the results of interest, especially expectations and efforts of the programme rated by the participants. To analyze changes the programme was able to achieve, we used t-tests to illustrate differences that occurred between the beginning and the end of the programme. This concerns the comparisons of dimensions of expectations and the barriers perceived by the participants. Structuring methods like factor analysis were used to analyze connections between variables – specifically to describe the dimensions of expectations the participants had towards the programme. As the questionnaire contained a set of various possible expectations, we tried to condense those

items into a smaller number of relevant dimensions to receive independent describing factors that contain correlating items. To find that underlying structure and to gain clearer parameters to describe our participants' expectations, factor analysis is a suitable, common method (for a critical investigation of the method, see Cureton & D'Agostino, 1983 or Bortz, 2010). We calculated a principal component analysis and extracted factors with an eigenvalue greater than 1 (Kaiser-criterion). To facilitate the interpretation of our factor solution, we used varimax rotation that maximizes variance between the factor loadings to get clearer distinctions between our possible factors. For our calculations we used SPSS 21.

4 Results

We first take a look at expectations before joining the network, which can be considered as motivations to take part, and subsequently compare the fulfilment of those expectations at the end of the network phase. We proceed similarly with the analysis of barriers hindering the implementation of efficiency measures and compare their perception at the beginning as well as at the end of network operations.

4.1 Expectations before joining the network

The participants were partially familiar with energy efficiency issues and had already implemented efficiency measures before the start of the network. For over half of the companies, energy savings have always been a relevant issue, according to their own declaration. 49% had received consulting on energy within the last 5 years. 18% of the companies already had experience of comparable networks on different topics (partially with energy aspects like ÖKOPROFIT or precursor projects, but also e.g. health management or specialists' networks). All companies voluntarily committed themselves to participating in the energy efficiency networks. Firstly, we had a closer look at the motivations and expectations with which the companies considered to participate. In order to get an idea of their anticipated benefits by joining an energy efficiency network, a first survey enquired about those expectations (see Table II-1).

Table II-1: Assessment of expectations at the beginning of the programme (5-point Likert-scale)

Expectation	N	Mean	Standard Deviation (SD)
Reduction of energy costs	278	4.79	.51
New ideas for reduction of energy costs	299	4.71	.52
Information about specific measures and technologies	299	4.57	.68
Information about energetic deficits	300	4.54	.61
Exchange of experiences	299	4.53	.70
Analysis of energy-related situation	289	4.39	.87
Information about profitability	300	4.36	.77
Support in priority setting of measures	287	4.20	.90
Reduction of transaction-costs (search and decisions)	285	4.15	.94
Confirmation of own ideas	299	3.97	1.00
Information about crucial planning aspects	300	3.86	.92
Information about difficulties in implementation	299	3.80	.99
Improvement of environmental image	275	3.76	1.13
Possibilities for exchange of measuring instruments	297	2.93	1.15
Possibilities for cooperative purchase of measuring instruments	299	2.91	1.18
Possibilities for cooperative purchase of energy	220	2.42	1.27

The five highest expectations (ranking 4.5 and higher) of the companies are the reduction of energy costs, followed by gaining new ideas, exchange of experiences in energy efficiency investments and organisational measures, information about specific measures or technologies and finding energetic deficits in their production sites.

Some participants used the “else”-category within the survey for own annotations on their expectancies towards the programme. 17 answers were given that way, e.g. expecting that contacts to other companies are established, comparisons to other companies and their energetic situation, meeting energy targets, or the preparation of certification or management processes.

The simple ranking of expectations (Table II-1) leaves unclear which aspects are seen as related in the perspective of our participants and which ones were key to take part in an energy efficiency network. A factor analysis was carried out to reveal the underlying structures in the ratings of expectations indicated by the respondents. It converged in four factors consisting of co-occurring expectations (see Table II-2).

Regarding those four dimensions, the expectations summarized under *practical knowledge and specific information* are ranked highest. The difference to the other dimensions is significant (compare Table II-3), difference to next lower ranked dimension *decision support by experience*: $T(299) = 9{,}835$, $p<.001$, as well as the differences between each of the

dimensions and the next lower ranked). The main motivations to take part in the networks are, besides the aim of reducing energy costs, to gather information about the energetic status on their production sites and to find suitable measures – the practical orientation (meaning implementations and actions and not only analyses and knowledge) is obviously highlighted. Cooperation for common purchase of instruments or energy seem less important.

Table II-2: Results of factor analysis (rotated, N = 210)

Items (expectation)	**Dimension**	**Mean of scale (SD)**
Reduction of energy costs *Analysis of energy-related situation* *Information about energetic deficits* *Information about specific measures and technologies* *New ideas for reduction of energy costs*	Practical knowledge and specific information	4.60 (.45)
Reduction of transaction-costs (search and decisions) *Exchange of experiences* *Confirmation of own ideas*	Decision support by experience	4.22 (.61)
Support in priority setting of measures *Information about profitability* *Information about crucial planning aspects* *Information about difficulties in implementation*	Organization and implementation	4.05 (.68)
Possibilities for cooperative purchase of measuring instruments *Possibilities for exchange of measuring instruments* *Improvement of environmental image* *Possibilities for cooperative purchase of energy*	Cooperation and image	3.04 (.90)

Bartlett's test on sphericity $Chi^2(120)= 1049.7$; $p<.001$; Kaiser-Meyer-Olkin measure=.815, which indicates our method as suitable (KMO>0.8 stated as "meritious", Kaiser and Rice, 1974).
We assume that points on our scale are equidistant and can be treated as interval.
Component matrix with factor loadings see Table II-5 in appendices.

4.2 Meeting the expectations

In a second step, we turn our attention to the changes the networks were able to achieve: On the one hand concerning the satisfaction of expectations, on the other hand concerning the reduction of barriers, which had impeded energy efficiency measures so far.

Within the surveys, the expectations in the beginning were ascertained (see above) and again their fulfilment at the end of the programme. The participants gave their ratings on a scale of 1 to 5 for each expectation. For our comparison between the ratings in the beginning and in the end, these expectations were summarized into the dimensions drawn from the factor analysis of expectations (Table II-2 above). A closer look reveals that concerning the dimension *practical knowledge and specific information*, expectations were fulfilled best, as it was ranked highest. The same dimension was ranked highest in the assessment of initial expectations (Table II-3). The difference to the next-higher ranked dimension *decision support by experience* again is significant ($T(178)=3{,}031$, $p<0.05$). The differences between each dimension and the next lower one are again also significant.

To find out if the network participation came up to what participants expected, a comparison between ratings at the beginning and end of the programme was calculated for the four dimensions (see Table II-3). The ranking of the dimensions' ratings is the same as in the first survey. As already spotted in the analysis of the first survey (pre), again the provision of practical knowledge and specific information is rated highest in the end (post). This means that this expectation is fulfilled best, but not as much as the participants anticipated in the beginning, as the significant difference between pre and post ratings show. The results show that the expectations regarding cooperation and image were ranked lowest, but were fulfilled as the participants anticipated them to be: There was no significant difference between the ranking of expectations and the ranking of the fulfilment of those expectations. All other expectations were a bit higher at the beginning (pre) than actually eventuated (post), although the general reported fulfilment of expectations in the end is rather high (minimum 2.99 on a scale from 1 to 5).

Table II-3: Comparison of expectations (pre=start of network) and their fulfilling (post=at the end of network)

Dimension expectation	Mean (post)	Mean (pre)	Difference	SD	T	df	Sig
Practical knowledge and specific information	4.06	4.60	.54	.74	9.734	177	***
Reduction of energy costs	3.70	4.84	1.14	1.10	12.91	154	***
Information about specific measures and technologies	4.01	4.60	0.58	1.12	6.85	172	***
Analysis of energy-related situation	3.86	4.38	0.51	1.10	6.03	167	***
New ideas for reduction of energy costs	4.22	4.69	0.47	0.99	6.31	175	***
Information about energetic deficits	4.20	4.59	0.38	0.94	5.36	171	***
Decision support by experience	3.93	4.22	.29	.85	4.566	177	***
Reduction of transaction-costs	3.49	4.12	0.63	1.39	5.33	137	***
Exchange of experiences	4.12	4.54	0.43	1.04	5.37	170	***
Confirmation of own ideas	4.07	3.99	-0.08	1.11	-0.98	165	n.s.
Organization and implementation	3.62	4.04	.42	.86	6.334	172	***
Information about difficulties in implementation	3.30	3.78	0.48	1.31	4.30	140	***
Information about crucial planning aspects	3.40	3.83	0.43	1.18	4.50	149	***
Support in priority setting of measures	3.81	4.16	0.35	1.36	3.24	161	**
Information about profitability	4.18	4.35	0.17	1.22	1.83	167	n.s.
Cooperation and image	2.99	2.93	-.06	1.26	-.556	142	n.s.
Possibilities for exchange of measuring instruments	2.41	2.95	0.54	1.52	3.20	81	**
Possibilities for cooperative purchase of energy	1.89	2.37	0.48	1.61	2.18	52	*
Possibilities for cooperative purchase of measuring instruments	2.63	2.89	0.26	1.42	1.71	84	n.s.
Improvement of environmental image	3.62	3.76	0.14	1.48	1.04	120	n.s.

Levels of significance: p<.05*, p<.01**, p<.001***, n.s.: not significant

Regarding the single expectations *confirmation of own ideas, possibilities for cooperative purchase of measuring instruments, improvement of environmental image, information about profitability* show no significant differences between the ratings in the beginning (pre) and in the end of the programme (post), which means that they were fulfilled the way the participants expected. In contrast, *reduction of energy costs* shows the most considerable difference between expectations in the beginning and their fulfilment at the end. Compared to items belonging to other dimensions, those belonging to dimension 3 achieve lower significance levels concerning the differences between ratings.

4.3 Overcoming the barriers

In the last sections, we considered if expectations could be fulfilled showing that the participants' needs to implement energy efficiency at their production sites were met. Considering barriers, we expect that their perception changed in the course of the programme, especially regarding information deficits, as the need for information was well satisfied in accordance with the participants' expectations.

Table II-4 shows a direct comparison between the reported barriers that existed or were expected in advance of the programme (pre) and those which were perceptible during and at the end of the programme (post). Because of the multitude of comparisons between the 11 items, a conservative assessment of the significance levels is done to avoid alpha inflation (alpha after Bonferoni-correction: 0.0045), that is why only highly significant differences are interpreted as substantial results.

Table II-4: Change of perception of barriers (beginning versus end of network operation)

	Barrier	Mean (pre)	Mean (post)	N	Difference	T	df	Sig.
1	*Concerned parties lack of time*	3.28	3.44	174	-0.16	-1.52	173	n.s.
2	*Measures not profitable*	3.19	3.12	172	0.07	0.59	171	n.s.
3	*Narrow financial possibilities*	3.02	3.31	121	-0.28	-2.25	120	*
4	*Missing energy management*	2.78	2.44	171	0.33	2.483	170	*
5	*Difficulties in implementation*	2.71	2.77	176	-0.06	-0.578	175	n.s.
6	*Staff hard to motivate*	2.70	2.59	175	0.1	0.943	174	n.s.
7	*Missing information or market overview*	2.62	2.03	173	0.59	5.469	172	***
8	*Departments hard to convince*	2.42	2.35	178	0.06	0.583	177	n.s.
9	*Only small share of energy costs in production costs*	2.17	2.62	169	-0.44	-4.057	168	***
10	*Management hard to convince*	1.89	2.15	179	-0.26	-2.622	178	*
11	*Manufacturer can't deliver*	1.74	1.73	128	0.01	0.081	127	n.s.

Levels of significance: p<.05*, p<.01**, p<.001***, n.s.: not significant; Table sorted by initial ratings (pre).

Thus, the barriers *only small share of energy costs in production costs* and the barrier *missing information or market overview* have changed during the programme: While the first one increased due to more awareness of this obstacle, the latter decreased as a consequence of the meetings and site visits. The reduction of the information deficit and lack of market overview should be considered as a positive assessment of the energy managers as they felt better informed about the possibilities of energy efficient solutions, one of their major motivations to join their network (see Table II-2, dimension 2).

4.4 Implementation of energy efficiency measures

The mere reduction of the barriers' size does not yet guarantee that energy efficiency measures are implemented. The success of the energy efficiency networks in terms of real energy savings, however, depends on the implementation of such measures. Therefore, the last step of our analysis was dedicated to the actual energy efficiency measures the participants reported to have implemented:

At the end of the programme, almost 96% (N=212) of those participants that filled in the last survey, reported that they implemented the suggested energy efficiency measures drawn out of the network process. This is considerably higher than the percentages reported in the introduction on the fulfilment of energy audit recommendations (cp. Gruber et al., 2011: 53% resp. 77% if planned measures are included). 75% (N=208) reported that a part of those measures would not have been implemented without the networks. As stated above, this led to an annual average improvement of efficiency of 2.1% (compared to 1% autonomous improvement) and resulted in about 5 PJ/a energy savings after 4 years.

In addition to that, about 75% of the participants rated the benefits of network participation as "rather high" or "very high", while about 73% evaluated the expenditure of time required for network participation as "low" or "rather low".

5 Discussion and conclusions

In line with our hypotheses, our results show that the participants of the LEEN are satisfied with their participation in their network as demonstrated by the high ratings for the fulfilment of their expectations. Especially their requirement for practical knowledge and specific information they needed to implement efficiency measures was met. The respective barriers of imperfect information and lacking market overview decreased. Most of the participants implemented measures that would not have been carried out without the networks. Thus, they were able to overcome other important barriers (like missing energy management, narrow financial possibilities or difficulties in implementation) while the perception of those barriers did not necessarily decrease. The matching of the programme to participants' needs seems to be a key success factor of the concept of the Learning Energy Efficiency Networks.

The results show that participants focused on practical information and support, less on organizational aspects. We interpret that the intensive processual supervision over 3 to 4 years and access to practical experience was the additional value seen in the participation in the networks, especially compared to other informative, more isolated one-time consultation like in energy audits, conferences, or individual workshops. Some experiences at the end were somewhat lower than the expectations. The reason for this change remains open as the answer could signal successful exchange of experiences during the meetings

and site visits leading to even higher expectations or some resignation caused by internal obstacles such as narrow financial possibilities and management who was hardly convinced (see Table II-4, no. 3 and 10). If they come up with additional energy efficiency investments, it is quite likely that it is harder to convince the management and the obstacle of limited financial possibilities becomes even more evident, particularly if those investments are financed by cash flow and not by additional credits. This goes in line with the findings mentioned above, that profitability and investment costs are focused when deciding about the implementation of energy-efficiency measures (Fleiter et al., 2012; Trianni et al., 2013b; Nehler and Rasmussen, 2015).

The barrier of a small share of energy costs in production costs increased. This share is between 0.7% in car manufacturing to 2.4% in metalworking and up to 8% in branches with heat and surface heat treatment (DESTATIS, 2014). Usually such small shares in production costs are common when energy efficiency has a low priority (Fleiter et al., 2012). Of course saving energy decreases energy costs, but the effect on the relation to total production costs is very small and energy efficiency is not considered to be a strategic investment (Cooremans, 2013). Harris et al. (2000) and Cooremans (2013) argue, that energy efficiency is often overlooked in companies because it is not "core business". Often energy-efficiency investments do not exist as an investment category, which makes them generally perceived as weak strategies by companies and therefore upper management is not interested in the investment project (Cooremans, 2013). To support the energy managers' additional financing possibilities (e.g. contracting, efficiency funds, crowd financing) could be developed as part of a new efficiency policy programme, to target financial restrictions. Emphasizing the high profitability of energy efficiency solutions may help to convince the management. In fact, recent analyses of the energy efficiency networks have already revealed that more than half of identified possible efficiency measures (3.600 of 7.000) were classified as profitable (IRR > 12%). Although low investment measures are those most frequently proposed (Roser, 2014), for each company an energy saving potential of about 2,700 MWh on average was identified, while the most profitable investments were expected in the areas of compressed air and electrical devices (Köwener et al., 2014).

As all companies implemented profitable measures suggested by the consulting engineer or one of the colleagues during the meetings, one can also reinforce the observation that further profitable options of energy efficiency investments and organisational measures beyond the already implemented measures do exist. Compared to other programmes, LEEN have achieved remarkable adoption rates of energy efficiency improvements (see section 4.4).

However, the perception of a barrier is an evaluation based on subjective information – and the level of information of the energy managers may have changed during the programme. This explains that the participants became more aware of the relatively low cost shares in production costs as an obstacle which also is reflected by increasing difficulties to convince the management in contrast to a slight improvement to convince the department (see Table II-4). This prompts that different barriers have more or less influence on implementing

measures, depending on the stage of decision making. Studies of Trianni et al. (2016) and Cagno et al. (2014) investigated that and found that barriers and drivers vary along the decision-making process of the adoption of energy-efficiency measures. It can be expected that the participants may have become sensitized by the involvement with those issues, which raised awareness for the barriers and therefore might have influenced the perception of their existence. Such sensitizing effects are a familiar issue in test theory, impairing internal validity of the analysis. A distinction between sensitizing effects and changes in companies' situations cannot be drawn on the basis of our questionnaires, but should be kept in mind for further research. Trianni et al. (2013c) dealt with that issue of perceived and real barriers investigating on energy efficiency in SME. For future network activities it may be very important that the management of a participating company is regularly informed by the energy manager and the consulting engineer taking the yearly monitoring results which can be a good occasion for a review meeting.

Interestingly, barriers are rated lower on average than expectations; this could reflect that for the participants, incentives such as high profitability or green image generation predominate despite the barriers.

We stated the information barrier/ lack of market overview as one major obstacle to be reduced by energy efficiency networks. We would have awaited or at least hoped for developments in the networks that positively influence the decrease of other surveyed barriers, too – which did not occur at a first glance. Looking at the monitoring data, intensive implementation of efficiency investments and reduced energy cost can be found which occurred mostly as a consequence of the networks, as stated by the participants.

One might hypothesize, that barriers do not necessarily need to all be simultaneously reduced, but can be often overcome for other reasons – maybe due to an informed decision, an upcoming competition among the network participants, or the present low level of interest rates. Furthermore, the implementation of some measures – e.g. additional small investments within a re-investment or organisational measures – may have even been that unexpectedly uncomplicated that they could be performed despite the perceived barriers. To check those assumptions, additional research should consider a deeper analysis of conducted measures, reasons for decisions and circumstances of their implementation.

Further research might take a closer look at the characteristics of those companies that named specific barriers as persistent, which might help to find target groups for corresponding offers. Like this, specific measures or technologies could be tailored to the specific problems and needs of the types of companies. In particular because we expect different barriers to be prevalent for different kinds of companies, as the work of Trianni et al. (2016) suggests, this might be an insightful attempt. Former research revealed that barriers to energy efficiency depend on factors such as company size, capital owners, energy intensity, management preferences, and high transaction costs (Jochem, 2014; Fleiter et al., 2013; Trianni, 2016). Mai et al. (2012) found that especially lesser energy-intensive SMEs face more barriers than other companies. Notably smaller enterprises (SMEs) tend to have

lower priority on energy efficiency issues (Cagno et al., 2010) and face more barriers (Fleiter et al., 2012). Schlomann and Schleich (2015) found company's characteristics influencing adoption of energy efficiency measures within the tertiary sector, but on the other hand little influence of sectoral heterogeneity on the adoption of low-cost energy efficiency measures. Suchlike differences apply to different measures, as Trianni et al. (2014) and Cagno and Trianni (2014) found barriers to vary according to the considered technology.

On the basis of this analysis of the questionnaires, we cannot answer the question if some of the participating companies with special characteristics benefit more than others from their participation. Roser et al. (2014) concluded that efficiency potentials through organisational measures depend on the energy intensity or the size of companies. Ownership of the company as well as the kind of sector (e.g. relatedness to the final customer) or internal circumstances (like routines of making decisions on investments or share of energy costs) also influence the realization of efficiency measures (Jochem/ Idrissova, 2014). First analyses led to the conclusion that lesser informed companies would reach the same or even better results in such energy efficiency networks and especially benefit from experiences and expertise of peer companies within the networks (Jochem/ Idrissova 2014).

Furthermore, the participants joined the programme voluntarily and some even already had energy audits before they joined their network. Because of that motivation and preparedness of most participants, the results are not representative for all companies of the branches represented by the 366 companies in the 30 networks.

Our sample consisted primarily of medium-sized and large firms of the manufacturing sector (cp. section 3.2). This means that a generalization of highly energy-intensive branches or small companies should be avoided. One of the recommendations (Di Nucci, 2012) was to examine if the concept of the energy efficiency network can be extended to smaller companies with yearly energy cost far below 0.5 million € per year. This extension was started in 2012 within the Foundation of Resource Efficiency and Climate Protection (2015) as a first pilot project in this target group.

Due to the lack of a systematic experimental design with control groups, the effects achieved during the programme cannot be broken down or traced back to single influencing factors and their impacts. Anyway we assume that especially the network as a local or regional entity exchanging company-specific information and involving facilitators (consulting engineers and moderators) made the effectiveness (compare Stern and Aronson, 1984). This suggests that this combination of informative, supporting, cooperative, involving, and monitoring elements of the concept of LEEN makes them a successful instrument targeting existing profitable efficiency potentials in industry, but also in trade, commerce, and crafts.

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Appendix

Table II-5: Rotated matrix of components for factor analysis on expectations

Item (expectation)	Extracted factors			
	Organization and implementation	Practical knowledge and specific information	Cooperation and image	Decision support by experience
Reduction of energy costs	-.081	**.738**	.175	.117
Reduction of transaction-costs (search and decisions)	.099	.348	.038	**.442**
Analysis of energy-related situation	.460	**.533**	.151	-.115
Support in priority setting of measurements	**.624**	.354	.177	-.084
Information about energetically deficits	.307	**.618**	.095	.043
Information about specific measures and technologies	.393	**.708**	.101	-.009
Information about profitability	**.715**	.220	.116	.035
Information about crucial planning aspects	**.833**	.045	.156	.165
Infos about difficulties in implementation	**.677**	.076	.187	.315
Exchange of experiences	-.060	-.008	.097	**.783**
Confirmation of own ideas	.350	-.007	.114	**.558**
New ideas for reduction of energy costs	.060	**.564**	-.025	.441
Possibilities for cooperative purchase of measuring instruments	.219	.020	**.840**	.153
Possibilities for exchange of measuring instruments	.155	.134	**.853**	.129
Improvement of environmental image	.075	.096	**.409**	.340
Possibilities for cooperative purchase of energy	.135	.159	**.747**	-.078

Method of extraction: principal component analysis.
Rotation: Varimax with Kaiser-normalization. [a]

a. The rotation converged in 9 iterations.

This table shows the factor loadings for each item. Highest loadings are highlighted in bolt and are the basis for the allocation of items to the underlying factors. The names of the factors more abstractly describe the items which are included in the factor.

Chapter III

Tailoring energy-efficiency measures to target groups – approaches regarding cross-sectional technologies and barriers in industry

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Abstract

The improvement of energy efficiency in industrial companies plays a crucial role for the energy transition. Although significant economic potentials have been identified, the concerned actors are still struggling to realise them fully. To support the implementation of energy efficiency measures by policies, a deeper understanding of the barriers affecting different kinds of companies is necessary to better match the options to their needs and requirements. This paper considers companies' characteristics and barriers to draw conclusions on energy efficiency policies and specific recommendations on energy efficiency measures. The recommends compromises for policies between high administrative effort for designing individual solutions for companies and too generic approaches, which are not tackling the specific barriers and characteristics of companies.

Our analysis assesses monitoring data of the Learning Energy Efficiency Networks LEEN in Germany, focusing small/medium sized enterprises (SME) and large enterprises (LE). This project supports energy audits, company networking and assesses implemented energy efficiency measures. We found financial barriers most prevalent, but there was no general correlation with company size. Audits are an effective information tool and are conducted more often by LE than SME. Lack of information combined with unfavourable reasoning in decision-making impedes the adoption of profitable measures. Thus, financial policy instruments should aim at promoting long-term decision-making. LE are stronger affected by motivational barriers, especially if the expected organizational effort is high. Reducing transaction costs can increase the willingness to invest greater efforts in energy efficiency measures. The number of implemented measures and the choice of specific measures relate to company size.

1 Introduction

Studies on energy efficiency and improving energy performance typically encounter the so called "energy efficiency gap" (Jaffe and Stavins, 1994; Stern, 1992), which is often referred to as the difference between the status quo and economically attractive energy-efficiency improvements. Barriers impeding improvements in energy efficiency issues need to be lowered to bridge this gap. A number of studies have already revealed the considerable potentials of energy-efficiency measures (Blok, 2004; Grenade et al., 2009; Worrell et al., 2009; Fraunhofer ISI et al., 2014; Ecofys and Fraunhofer ISI, 2010; Eichhammer, 2013). Accordingly, improving energy efficiency has received increasing attention in energy policy in many countries (IEA, 2012).

The technical potential of EEMs (energy efficiency measures) in companies is limited by the available processes or technologies where measures can be applied. However, previous studies have already shown that non-technical barriers tend to be the main obstacle to implementing EEMs (IEA, 2012). The energy efficiency gap must be ascribed to barriers that are associated with internal routines, procedures or decision making, ways of reasoning, organizational or financial possibilities and external restrictions (cp. Sorrell, 2011). Recent research differentiates between economic, information-related, organizational, behavioural, competence-related, technology-related and awareness barriers (Cagno et al., 2013). Previous work has shown that companies often have misconceptions about the profitability of energy efficiency measures – taking risk indicators such as pay back period as profitability indicator (Schöter et al., 2009). Especially if energy intensity is low, improvements in energy efficiency might be underrated (Harris et al., 2000; Cooremans, 2013), possibly due to a lack of information to fully assess its value. Especially SME might not be able to reduce their uncertainties because of lack of time and money to afford these transaction costs (Stern and Aronson, 1984). Providing information first and then accompanying the steps of the implementation process of measures can lead to significant improvements in energy efficiency despite the existence of other, not only informational barriers (cp. Wohlfarth et al., 2016). Trianni et al. (2016) provide an overview of empirical studies on barriers to industrial energy efficiency, highlighting the decision making process. These aspects should also be taken into account when EEMs are suggested.

The persistence of these barriers is one important justification for the introduction of policy instruments[1] in the field of energy efficiency aiming at overcoming the barriers and thus fully exploiting the cost-effective potential. Typically, regulative, informative and economic policy instruments can be distinguished (Rogge and Reichardt, 2013). Policy measures targeting SME can predominantly be classified as financial or informational/ educational measures, while the majority of the existing measures fall under the category of financial

1 Policy instruments are concrete tools to achieve overarching policy objectives such as the removal of barriers. The term 'instrument', can also be described in studies as 'implementing measures', 'programs', 'policies', or 'policies and measures' (for a comprehensive overview see Rogge and Reichardt, 2013).

measures (funds, loans, subsidies, financial support schemes, subsidised consultations, financial incentives and aids). Informational/ educational measures include resource planning and management and the behavioural training of employees towards more responsible energy-related practices (Lapillonne et al. 2015). An overview of typical barriers and remedial policy tools is given in IEA (2012) and EEFIG (2015). Ringel et al. (2016) and Fleiter (2013) give indications of the saving potential, which can be exploited by the respective policies.

However, each of these instruments usually only addresses parts of the barriers. Therefore, several policy studies in the field of environmental research have argued for the need to combine different policy instruments in so-called policy mixes (see Rogge and Reichardt, 2013, for an overview). Concepts like the German National Plan for Energy Efficiency (NAPE) combine instruments for information and market transparency, financial incentives and regulations in a broad policy mix to address different barriers and enhance the implementation of EEMs. A suitable policy mix to support the implementation of energy-saving measures in companies might also make use of scarcely addressed driving forces like social and psychological factors (e.g. improved motivation of energy managers, environmental awareness or a better public image, cp. Lapillonne et al. 2015).

It is already known that companies' characteristics influence implementing EEMs, e.g. manufacturing companies are more active than those from the tertiary sector (DeCanio & Watkins, 1998) and larger companies are usually more likely to invest in energy-efficiency technologies (ib., Florax et al., 2011; Trianni & Cagno, 2012; Arens & Worrell, 2014). A policy instrument differentiating between companies' characteristics (in this case companies' size) by addressing informational deficits, is Article 8 of the Energy Efficiency Directive EED (EC, 2012). It requires Member States since 2015 to implement a four-yearly energy audit obligation for LE and to develop programmes to encourage small or SME[2] to voluntarily undergo energy audits and to implement audit recommendations. Although audits for SME are not mandatory, they seem especially important as SME are usually less aware of EEM options (cp. Table III-5 and Table III-7) and therefore tend to underestimate their potential (Gruber & Brandt, 1991; Frahm et al., 2010). It should be noted that the majority of companies in Germany belong to the category of SME (Statistisches Bundesamt, 2013), as in most countries. The energy consumption of an SME is indeed lower than for LE in the same sector, but in sum they remain important energy consumers. Their potential for energy efficiency improvements is typically more cost-effective, as it is largely untapped and improvements can already be made with lesser effort (IEA, 2015; Thollander et al., 2014). While several EEMs are already in place in a variety of countries for SME (cp. Price and Lu, 2011; Fleiter et al., 2012; IEA, 2015), more tailored programmes are needed to deal with their special needs (Trianni & Cagno, 2012; Trianni et al., 2016).

2 The definition criteria for SME are in this case: number of employees, turnover and balance sheet total (EC 2003).

In order to give recommendations for policies, a connection between types of companies and barriers should be drawn to identify specific target groups for specific policy measures. According to Stern and Aronson (1984), effective information is specific and personal, so the aim is to personalize and specify EEMs to target groups. The idea is to differentiate policies and EEMs more adequately without the need of an individual audit for every single company. This more general approach could be a marketing strategy that reduces the effort needed for searching and information processes and could also serve as the basis for recommendations addressing company-types on a larger scale. On the other hand, knowing about the differences between target groups allows the promotion of energy efficiency policies to be tailored to their needs.

Hence, taking SME into the focus, the research questions of this paper are:

- Which kind of barriers hindering the implementation of EEMs are the most prevalent and are they related to specific types of companies?
- On which general company characteristics (like size, energy costs or autonomy in decision making) does the potential to implement measures depend?
- Are specific measures a better fit for specific kinds of companies?
- How can the present policy mix addressing companies be improved based on the results of our analysis?

2 Methods and data base

2.1 Methods

For our analyses, we use evaluation data from a project that aimed to identify and implement EEMs in companies – namely from LEEN "Learning Energy Efficiency Networks" (Jochem and Gruber, 2007; Rohde et al., 2015) – focusing on companies from the manufacturing sector. The LEEN addressed small and medium-sized enterprises (SME) and large enterprises (LE).

We analyze the relations between companies' characteristics and barriers respectively implemented measures to find categories of target groups and suitable support measures. We compare SME with LE in a more detailed analysis and try to derive policy implications from our results. Rating scales for barriers during the implementation process of EEMs as well as the number of implemented measures and a broad collection of company characteristics for SME and LE were taken from the LEEN data. The items for barriers were worked out by the project team based on long-time experience with comparable projects (Jochem and Gruber 2004; Jochem and Gruber, 2007; cp. DiNucci, 2012). The categorization of measures (cp. Table III-8) was developed within a bachelor thesis (Leinweber, 2014) by clustering those measures that were recorded during the monitoring of the project by the

criteria 'kind of measure' and 'location of implementation'. The technologies the categorized measures refer to are thereby treated as an entity, i.e. measures are not counted twice (e.g. measures on pumps are not included in measures on refrigeration although the refrigeration system may contain pumps).

Besides descriptive statistics, we used factor analysis to describe the relevant dimensions of barriers to the implementation of measures. Factor analysis is a method to reduce complexity in data by combining similar variables to factors which describe different underlying concepts. Above all, we tried to draw connections between companies' characteristics and variables of interest (like barriers or the number of implemented measures) using regression analyses. A regression analysis estimates the relationship between variables – a dependent variable and different independent variables (here companies' characteristics). The aim is to understand how the dependent variable changes when the independent variables vary (see Howell, 2012).

Typically, the formula for a regression analysis can be expressed as:

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

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

To analyse differences between subgroups, we used t-tests – a method that analyses differences of means for significance.

2.2 Database

Our analysis is based on detailed monitoring data from the scientific evaluation of the Learning Energy Efficiency Network process in Germany between 2009 and 2014. Participants in such a network are committed to regularly exchange experiences in regional groups of 10 – 15 companies and to set themselves a voluntary energy saving target for the next 3 – 4 years. A fee is paid by the companies to finance the energy audit, network meetings and monitoring. For our analysis, we especially drew on the evaluating survey data collected towards the end of the networking process (second half of 2013) and monitoring data on the implemented measures in each company. We merged these data for our purpose, but due to the different sources, available data may differ for the individual companies (Table III-1).

Table III-1: Available data from LEEN used for the analyses

	Total available data for companies from the manufacturing sector	**Data available from evaluating survey**	**Data available on implemented measures**
Number of participants	263	160	137

Those companies can be assigned to the manufacturing sector (NACE classification sector C[3]), especially the subsectors manufacture of food products (NACE 10), chemicals and chemical products (NACE 20), rubber products (NACE 22), basic metals (NACE 25) and machinery and equipment n.e.c (NACE 28) (each between 7.6 and 13.3%, remaining subsectors with smaller shares). These rather small groups of subsectors impeded analyses on the basis of subgroups within the manufacturing sector. Therefore, conclusions on the influence of core businesses and underlying production processes are hardly possible for our dataset. We tried to consider structural effects anyway by grouping subsectors by energy intensity of their processes (Table III-2). Category 2 is used as reference category for our regression analyses.

Table III-2: Clustering of subsectors for LEEN dataset

N = 263	**1 low energy intensive processes** n=50 (SME = 24%)	**2 medium energy intensive processes** n=116 (SME = 33%)	**3 high energy intensive processes** n=97 (SME = 53%)
(NACE) Subsectors of manufac-turing sector	(12) tobacco products (14) wearing apparel (15) leather and related products (16) wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (18) printing and reproduction of recorded media (21) basic pharmaceutical products and pharmaceutical preparations (26) computer, electronic and optical products (27) electrical equipment (31) furniture (33) Repair and installation of machinery and equipment	(10) food products (25) fabricated metal products, except machinery and equipment (28) machinery and equipment n.e.c. (29) motor vehicles, trailers and semi-trailers (30) other transport equipment (32) other manufacturing	(13) textiles (17) pulp and paper products (19) coke and refined petroleum products (20) chemicals and chemical products (22) rubber and plastic products (23) other non-metallic mineral products (24) basic metals

3 Industrial sector classification, see http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

The set of companies is not representative regarding the shares of company size (cp. Table III-3). This is because participation in the LEEN was recommended especially to medium-sized and large companies with annual energy costs between €0.5 and 50 million because otherwise participation in the networks would have been too costly for companies in comparison to expected savings.

Table III-3: Overview of analyzed datasets

Data described as mean (Median Md; Standard Deviation SD)	**Learning Energy Efficiency Networks LEEN**		
	Total number of manufacturing companies	**SME**	**LE**
Number of companies (N)	263[4]	95	150
Number of employees per company	635 (331; 957)[5]	122 (119; 65)	961 (565; 1108)
Energy costs Mio €	2.95 (1.54; 4.44)	1.34 (0.68; 2.01)	4.07 (2.38; 5.35)
Energy intensity (MWh/ employee)	183.97 (49.01; 463.71)	259.24 (75.13; 583.47)	135.98 (43.01; 361.77)
Implemented measures per company	12 (8; 10.7)	8.48 (6; 7.7)	13.87 (11; 11.8)
Audit already conducted (%)	48.4	37.2	56.9
Share of cluster 1; 2; 3 (%)	19; 44; 38	12; 37; 52	23; 48; 29

Definitions of companies' sizes: SME (<250 employees); LE (>=250 employees)

3 Results

3.1 The influence of barriers

We first evaluated LEEN participants' ratings of the barriers at the end of the networking process, asking which ones were observed during the network phase. So those barriers refer to the perspective of the companies as energy consumers (not to manufacturers of energy efficiency technologies, consultants or banks). This especially concerns the barrier *measures not profitable*, because the measures suggested by the energy consultants are expected to be profitable. The rating given for this category reflects the perception of the person in charge within the company which might be different to the one of the consultant (e.g. due

4 Number of companies does not sum up to total number, because data for number of employees (used as classification for SME or LE) was not given for all companies.

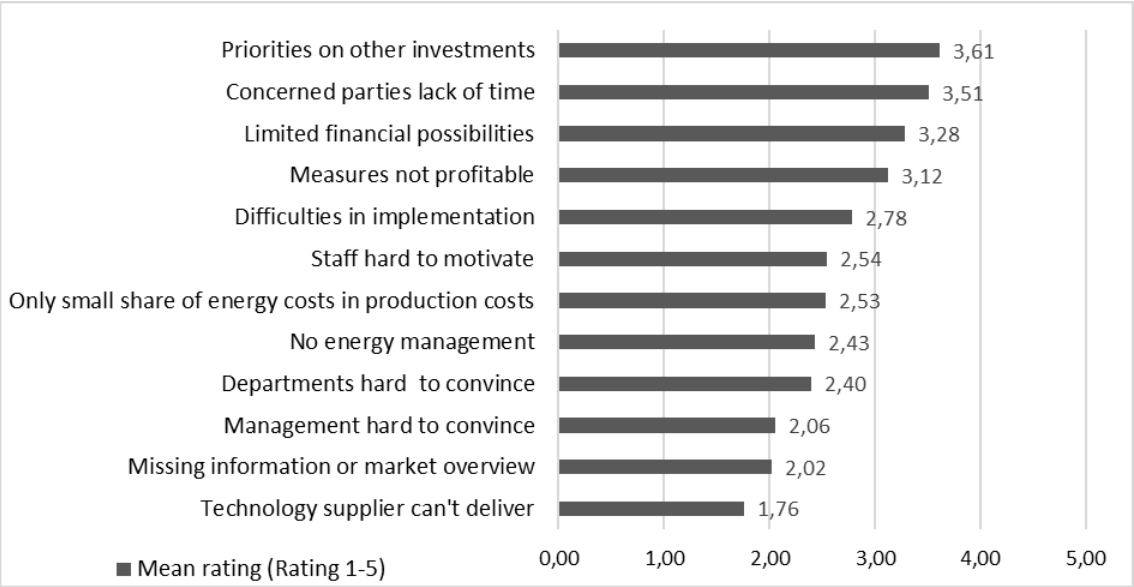
5 Due to the large spread we assume that some indicated employees for the whole corporation.

to internal rates of return). Figure III-1 shows the mean ratings as well as the overall ranking of barriers. *Technology supplier can't deliver*[6], *missing information or market overview* and *management hard to convince* are ranked the lowest, which is comprehensible because technologies for suggested measures were available and one main issue within the network process was delivering information. Concerning management approval, one can assume that management was already generally convinced of the idea of implementing efficiency measures, because this was the purpose of the project they chose to participate in.

The barriers ranked the highest mostly concern issues of time and money with a clear emphasis on financial restrictions: *Measures not profitable, limited financial possibilities, concerned parties lack time* and *priorities on other investments*. The difference between *difficulties in implementation* and the higher ranked barriers with values greater than 3 turned out to be significant (T(157)=2.653**)[7].

Overall, the ratings are quite moderate with a mean of 2.7 on a scale from 1 to 5 (1: a low rating of the barrier; 5: a high rating). One should note that, at the end of the project, over 96% (N=153) of the participants that completed the last survey reported that they implemented at least some of the suggestions resulting from the network process. This supports the assumption that the networks did well in addressing possible barriers. This also means that the barriers stated here did not prevent measures in general, but did at least hinder the process or impede the implementation of additional suggested measures beyond those that have been implemented.

Figure III-1: Rating of barriers to energy efficiency measures during the network phase



6 This refers to material and technology needed to implement the energy efficiency measure of interest.

7 level of significance: * = p≤.05, ** = p≤.01; *** = p≤.001

We assume that companies usually are affected of more than one barrier when they are struggling to implement measures, and that some barriers are more likely to co-occur. The simple ranking of barriers does not indicate which aspects interact or are regarded as interrelated from the perspective of the participants. Therefore, we conducted a factor analysis with the aim to find underlying structures and content-related categories in the ratings of barriers mentioned by the participants. Table III-4 shows the resulting four factors which consist of co-occurring barriers.

Table III-4: Categories of barriers

Items (barriers)	Factor (category)	Mean of scale (SD)[8]	Taxonomy cp. Cagno et al. (2013)
• Limited financial possibilities • Priorities on other investments • Measures not profitable	**Financial/ economic restrictions**	3.33 (.98)	economic barriers
• Difficulties in implementation • No energy management • Concerned parties lack of time	**Constraints in technical/ structural circumstances**	2.90 (.83)	organisational, technology-related and competence-related barriers
• Management hard to convince • Departments hard to convince • Staff hard to motivate • Only small share of energy costs in production costs	**Motivation/ internal relevance**	2.38 (.79)	behavioral barriers
• Missing information or market overview • Technology supplier cannot deliver	**Deficits in information or external market-related factors**	1.90 (.79)	information-related/ awareness barriers

Bartlett's sphericity test $Chi^2(66)= 343.0$; $p<.001$; Kaiser-Meyer-Olkin measure=.612 (moderate, Kaiser and Rice, 1974).

The identified factors are in line with taxonomies of barriers in other studies. Compared with one of the later taxonomies introduced by Cagno et al. (2013), which distinguishes economic, information-related, organizational, behavioural, competence-related, technology-related and awareness barriers, we found some of these categories concurred in our case. We therefore used a smaller set of items on which to base our categories. We assigned economic barriers to "financial/ economic restrictions", organizational, technology-related and competence-related barriers to "constraints in technical/ structural circumstances", behavioural barriers to "motivation/ internal relevance" and information-related and awareness barriers to "deficits in information or external market-related factors". In the following, we rely on those categories for further analyses instead of single items.

8 The means of scales do not differ in their ranking order comparing SME and LE

We conducted regression analyses to examine whether the categories of barriers are dependent on specific characteristics of the participating companies, using barriers as the dependent variable. The following company characteristics were treated as independent variables: number of employees, energy intensity (annual MWh per employee), energy costs, autonomy of enterprise, relatedness to customer and how EEM decisions are made (stating that the decision is influenced by organizational effort, profitability calculation, amount of expenses or else) (Table III-5).

Table III-5: Factors influencing barriers

Factor	Variables of significant influence (β)	Model quality
Financial / economical restrictions	Decision based on amount of expenses** (0.18) Autonomy of enterprise*[1] (0.13)	F(10)=2.513** R^2=.091 (.055)
Constraints in technical / structural circumstances		n.s.
Motivation / internal relevance	Number of employees*** (0.26) Energy costs* (-0.18) Cluster subsector 3 (-0.15)	F(10)=2.330** R^2=.084 (.048)
Deficits in information or external market related factors		n.s.

R^2: explained variance; F: test value for significance; level of significance: * = p≤.05, ** = p≤.01; *** = p≤.001
[1]0: autonomous, 1: part of another corporation. Relatedness to customer means that products are directly supplied to end customers.

The analysis showed that especially motivational and financial barriers are more prevalent in specific kinds of companies (Table III-5): Larger companies, companies with lower energy costs and companies that do not belong to those with energy intensive processes (cluster 3) tend to face motivational barriers to a stronger degree. We assume that more effort is required to motivate a larger number of employees resp. the management of LEs and that lower energy costs act as a demotivating force as well as missing energy intensive processes where saving potential could be found. Autonomous companies (which might be able to make decisions concerning expenses on their own) are affected to a lesser extent by financial barriers as are companies that do not base their EEM decisions only on expenses. This suggests that the way of decision-making affects the barriers to EEMs.

Regulations, directives and entitlements sometimes distinguish between company types mainly based on company size. Our analysis showed that company size has a highly significant influence on at least one of the barrier factors. We assume that the influencing variables differ within different kinds of companies, so in order to reveal other factors, which might be overlooked under the influence of the number of employees, we decided to conduct the same regression analyses within the two subgroups of SME and LE (cp. Table III-3 for group sizes and information on their characteristics). Table III-6 shows the results.

Table III-6: Factors influencing barriers in SME and LE based on LEEN

Factor	**SME**		**LE**	
	Variables of significant influence (β)	Model quality	Variables of significant influence (β)	Model quality
Financial / economic restrictions	Decision based on amount of expenses*** (0.46)	F(10)=3.671***, R^2=.304 (.221)		n.s.
Constraints in technical / structural circumstances	Number of employees** (0.36) Energy costs* (-0.35) Decision based on amount of expenses* (0.27) Decision based on organizational effort** (0.30)	F(10)=2.335*, R^2=.217 (.124)		n.s.
Motivation / internal relevance	Energy intensity** (0.46) Number of employees* (0.26) Energy costs* (-0.40)	F(10)=2.607**, R^2=.237 (.146)	Number of employees* (0.21) Decision based on organizational effort** (0.25)	F(10)=2.505**, R^2=.153 (.092)
Deficits in information or external market-related factors		n.s.	Decision based on amount of expenses** (-0.27)	F(10)=2.388*, R^2=.147 (.085)

R^2: explained variance; F(df): test value for significance
Level of significance: * = p≤.05; ** = p≤.01; *** = p≤.001

This more detailed analysis reveals differences between SME and LE concerning characteristics that influence barriers. Comparing the results for SME and LE, the effects of characteristics are more strongly and more frequent for SME, indicating a larger heterogeneity within that category. Energy intensity, the number of employees and small energy costs indicate greater motivational barriers for SME. The analysis shows that energy intensity and energy costs are perceived differently. While high energy costs serve as motivating factor, high energy intensity in SME can have the opposite effect. High energy intensity means high consumption for few employees – indicating energy consumption being a (mostly) inevitable part of the core business and/ or possibly no persons for energy

management in charge. In particular, small enterprises are more likely to not have a person responsible for energy issues, which might also explain motivational barriers. Compared to high energy costs, high energy intensity alone may therefore not be sufficient to motivate companies to introduce changes. Alike for this subgroup of SME as for the complete sample, a larger number of employees seems harder to be motivated while higher energy costs can serve as motivating factor. For LE, motivational barriers occur when great organizational effort is expected, e.g. the activity of responsible or affected employees. For LE, too, a larger number of employees is harder to motivate. In SME, financial barriers are perceived to be higher if EEM decisions are based only on the amount of expenses rather than other reasons. Having the mere sum of money in mind, expensive measures which are profitable in the long rum might be impeded. For LE, deficits in market-related factors are perceived to be smaller when decisions are based on the amount of expenses. We assume that if the available budget respective to cash flow is low, interesting measures or technologies are perceived as unaffordable – regardless of whether the investment would be profitable considering longer payback periods. If budget is high enough to afford investments, the aspect of the information-barrier "*technology supplier cannot deliver*" might become more important. For SME, constraints in circumstances like difficulties in implementation or lack of time are associated with a larger number of employees, low energy costs (that might not justify the effort) and if decisions are based on amount of expenses or (quite reasonably) on organizational effort.

3.2 Factors influencing the implementation of measures

Complementary to the analysis of companies' characteristics concerning barriers, we also conducted a comparable regression analysis for the absolute number of measures the companies implemented (dependent variable) to find out whether becoming more energy efficient is easier for certain kinds of companies than for others.

Table III-7: Regression on number of implemented measures

Factor	**Variables of significant influence (β)**	**Model**
Number of implemented measures	Number of employees** (0.22)	F(10)=2.466**, R^2=.089 (.053)

R^2: explained variance; F(df): test value for significance

Level of significance: * = p≤.05, ** = p≤.01; ***= p≤.001

Our result shows that the number of implemented measures usually increases with the number of employees (Table III-7), most likely due to a concomitant larger production site, i.e. more facilities and technologies available for EEMs. The effect has a low level of explained variance resp. is only relevant for large differences in the number of employees. This prompts why no such effect was found within the subgroups of SME and LE. In contrast to companies' characteristics, a similar regression analysis examining the influence of

stated barriers on the number of conducted measures revealed no significant results. We do not imply that perceived barriers had no influence on the process of implementing efficiency measures, but with this result in mind, we did hypothesize that companies facing specific barriers tend to implement different measures than companies facing other barriers. If barriers vary between EEMs this information can be useful when suggesting EEMs to companies facing specific barriers (cp. Sorrell et al., 2011, Cagno & Trianni, 2014). We used T-tests to see whether the values of stated barrier dimensions and other characteristics varied between those companies that conducted specific types of measures and those that did not (Table III-8).

Table III-8: Energy efficiency measures and company characteristics influencing implementation

Energy efficiency measure	**Company characteristics influencing measure implementation**	**Average difference in company characteristics**	**Test value for significance**
production of heat	-		
refrigeration	-		
ventilation and air-conditioning technology (VAC)	Larger number of employees Lower energy intensity Less often cluster 3	488 vs. 1122 283.48 vs. 102.47 MWh/ empl. 41% vs. 30%	T(44.0)=-2.449* T(108.2)=2.390* X^2(1; 137)=6.58*
lighting	Higher motivational barriers	2.22 vs. 2.66	T(83)=-2.654**
compressed air	Higher motivational barriers	2.31 vs. 2.69	T(83)=-2.312*
building envelope	Lower energy intensity More often in cluster 2	267.62 vs. 80.98 MWh/ empl. 41% vs. 58%	T(115.2)=2.822** X^2(1; 137)=4.90*
utilization of waste heat	Lower energy intensity	291.89 vs. 118.81 MWh/ empl.	T(89.5)=2.139*
motors and pumps	Higher organizational barriers	2.88 vs. 3.23	T(83)=-2.082*
distribution of heat, cooling and compressed air	-		
organizational measures	Larger number of employees	449 vs. 908	T(84.3)=-2.582*
other measures	Higher energy intensity	119.24 vs. 296.10 MWh/ empl.	T(111.5)=-2.035*

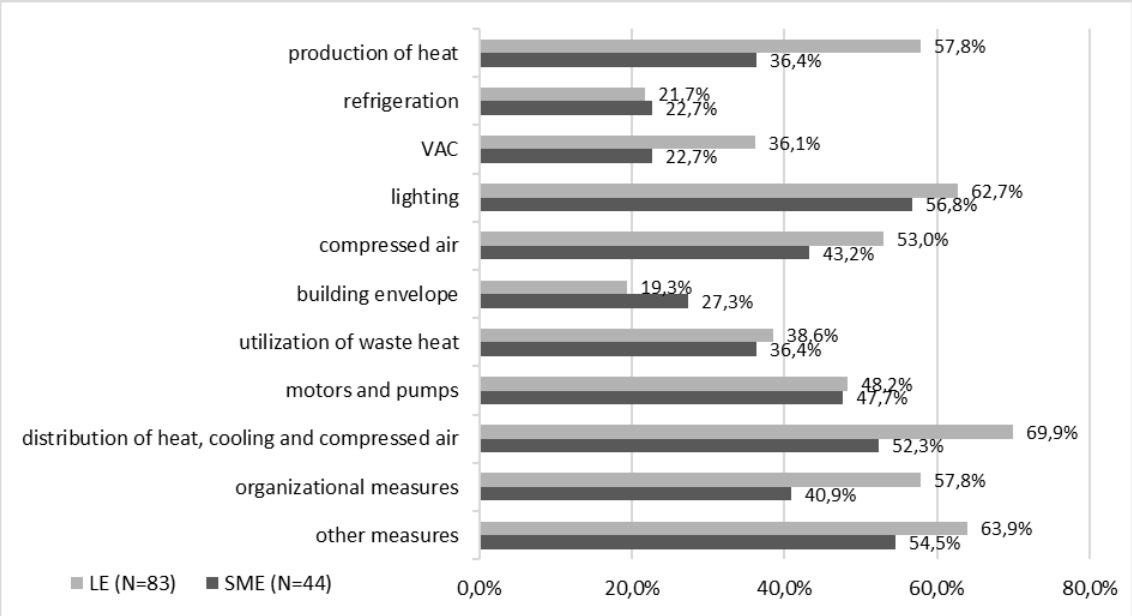
Level of significance: * = p≤.05, ** = p≤.01; ***= p≤.001
Independent variables: Barriers, number of employees, energy intensity
Barriers measured on a scale of 1 to 5, energy intensity: MWh/employee, cluster: share within cluster that implemented concerning EEM compared to share in other cluster

VAC (ventilation and air-conditioning) measures are more often implemented by larger companies with lower energy intensity which can be expected, as these characteristics prompt a higher importance of energy consumption due to building issues than for processes. The dimensions of VAC are probably correlated with the number of employees and therefore makes such measures more profitable in larger companies. Organizational measures (such as staff motivation) also seem more sensible and maybe more necessary given a larger number of employees. Lighting or compressed air measures seem to be feasible with lesser effort as they are especially implemented in companies with high motivational barriers. Measures concerning the building envelope can also be suitable for companies that lack technologies with energy efficiency potential or if they have low energy intensity. The latter might apply as well to the use of waste heat. Change or control of motors and pumps seem to be measures which can be implemented with comparatively low organizational effort.

Measures dealing with process heat or an energy carrier change usually deliver the highest absolute savings. On the other hand, these measures also require high investments (Rohde et al., 2015). Cost-effective saving potentials in industry can be found especially in the field of cross-cutting technologies such as motors (fans, pump systems, cooling devices, compressed air systems) and electricity-driven system optimisation or CHP (Lapillonne et al. 2015).

Figure II-2 compares the implemented measures for SME and LE. Differences in specific measures can be seen for the production of heat, VAC and distribution of heat, cooling and compressed air, which are all conducted more by LE than SME. In general, lighting, distribution of heat, cooling and compressed air and motors and pumps are among the most implemented EEMs in SME. The figure shows, that some measures are more common than others although the concerning technologies are available for all companies (e.g. efficiency measures concerning lighting compared to measures concerning the building envelope – indicating that lighting measures can be conducted with much lesser effort). As stated above, LE usualy conduct more measures, but the rates of implementation are not always in relation (comparing measures on motors and pumps with production of heat). In few cases, measures are more common for SME (esp. measures for the building enveope).

Figure III-2: Comparison of conducted measures for SME and LE within LEEN



When interpreting these results, one should mind that there might be structural differences between the subgroups of SME and LE. E.g. there is a larger share of companies with energy intensive processes (cluster 3) in the subgroup of SME than in the group of LE (cp. Table III-2). It should be noted that these rates of implementation of measures is rather high, because the companies participated the LEEN, which plays a crucial role in influencing the implementation of EEMs.

4 Discussion

Our analyses aimed at gaining deeper insights into the relations between companies' characteristics and barriers resp. implemented measures in order to draw conclusions for a better tailoring of measures to specific companies.

To tailor instruments well to groups of companies, they should be related to relevant companies' characteristics. Trianni and Cagno (2012) highlight that characteristics additional to companies' size (e.g. experience and sector) should be taken into account when considering energy efficiency barriers and options, furthermore SME cannot be regarded as homogenous group. Our results support these findings: companies' size turns out to be an important factor, but concerning barriers and the implementation of EEMs, several other factors turn out to be influencing as well – even within the groups of SME and LE. Our investigations consider companies' size and energy consumption resp. energy intensity as well as other attributes that might influence implementations of EEM like autonomy of enterprise, relatedness to customer, how EEM decisions are made and energy

intensity of processes. Finding those characteristics linked to barriers or successful implementation of EEMs allows recommendations or customizing instruments for target groups.

Within our analyses, the barriers assessed as highest concerned the availability of time and money which somehow reflects the minor priority for energy efficiency compared to core business issues. This confirms the findings of comparable studies in the literature, e.g. Fleiter et al. (2012), where high investment costs, other priorities and unprofitable measures were found to be the most important barriers in SME, or Thollander et al. (2007), who investigated less energy-intensive SME in the Swedish manufacturing sector and concluded lack of time and the low priority of energy efficiency to be the main barriers. Anderson and Newell (2004) found that too high initial expenditures were the most often mentioned barrier, followed by a lack of staff for implementation and limited cash flow preventing implementation. They also point out institutional and bureaucratic barriers, which are hard to ascertain, because the given reasons are rather vague. A large share of companies (about 85%; Schröter et al. 2009) base decisions on short payback rates and therefore often reject profitable measures that would have been adopted if the internal rate of return had been taken as the decision criterion (Jochem et al., 2010). Trianni and Cagno (2012) found lack of capital and insufficient information about opportunities and for decision making to be the highest ranked barriers, while lack of time and access to capital seemed more prevalent in smaller companies.

The companies we based our analyses on belong to the manufacturing sector and have in common that they were prepared to make decisions on EEMs, i.e. they were informed about their opportunities and received suggestions of suitable measures. We focused on cross-cutting technologies which apply for many sectors, however our results should be verified for different sectors than the ones of our sample. Our data is limited to companies from the manufacturing sector that participated voluntarily in the LEEN. Therefore, we can assume that our results cannot be generalized to other sectors and are likely to be biased in their level of conducted measures by the self-selection of (perhaps especially ambitious and interested) participants. Barriers due to information deficits were ranked low, but should not be underestimated – in our case, information was delivered within the project in which our sample participated.

To refine those analyses in order to describe target groups, the single subsectors should be considered as a describing variable to allow tailoring measures also to sectors. We did not add this kind of company characteristics, but created sector clusters, because our sub-sample sizes were too small for statistical relevance (mostly <5 companies/ subsector). Especially for the definite comparisons of conducted EEMs between target groups, analyses regarding subsectors might give deeper insights. A mere differentiation between SME and LE might be too vague; generally, we expect differences between the distribution of subsectors between SME and LE that need to be taken into account tailoring policy instruments to target groups. Future extension of policy instruments like the LEEN will provide larger data sets which can be exploited to gain more insight at sector level. Such

type of analysis should be carried out in a timely manner and results fed back to the improvement of policy measures.

Comparing findings for different industrial sectors faces the problem that studies differ by sector, technologies, time or considered barriers – as well as methodology. Additional insights could be gained from conducting analyses with a sample of sufficient size (e.g. future extension of LEEN, BMWi, 2014, 2016; dena, 2015), containing subgroups with appropriate sizes for subsectors. Ideally, the sample should be representative as we observed data differences in the structure of our subgroups of SME that might influence the statistics.

5 Conclusions and recommendations

Regarding the most prevalent barriers for the implementation of EEMs, financial barriers are rated highest. But our analysis also indicates that a more detailed look needs to be taken to understand the causes in order to find solutions. Financial barriers can be caused by e.g. lack of capital, bureaucratic issues, no autonomy in decision making about expenditures or other priorities. High scores in this barrier are often influenced by the criteria of decision making, e.g. if they are based simply on the amount of invested money and neglect profitability, or if the assessment of profitability is made with the unsuited risk indicator of payback periods. Our analyses revealed this influence is especially high in SME. It can be assumed that all the suggested measures are not unaffordable per se, and generate very high profits after the break even. But most companies seem to be very risk averse or they are not aware that they vote against high profits when deciding on a two or three years pay back period. Funding or other financial support can lower this threshold if decisions are based on the amount of expenditure. In these cases, financial restrictions are declared to be a barrier, but the financial policies introduced to tackle them might actually confirm this short-sighted way of thinking. It might be better for future policies to *incentivize more forward-looking investment behaviour* rather than funding the shortfall to measures which are not classified as profitable due to suboptimal decision criteria. The pro-active development of energy-efficiency investment options by financial institutions can support decision making of companies. In cases where unaffordable equipment still hinders the implementation of efficiency investments, contracting or leasing could be another option. Findings from the LEEN show that this risk perception can be lowered by exchanging experiences among energy managers in meetings of energy efficiency networks. Assuming their smaller financial possibilities, audits and programmes accompanying implementation like LEEN need to be less costly (cp. Mari:e networks, Foundation of Resource Efficiency and Climate Protection, 2015). This indicates that *informational measures should not be limited to the period before implementation*, but are also required beyond the phase of identifying options. More hesitating companies possibly need more communication and the *model of*

pioneer companies to be convinced. This should be kept in mind for the design of policies or when making efforts to upscale the effects.

Lack of time also is a high ranked problem and might especially affect companies which do not have a person in charge of energy issues. But this may also reflect the reluctance about transaction costs that can only partially be overcome by funding the investment costs, because implementation also takes time and effort for gathering information, searching for options and bargaining. Lowering these transaction costs would support the implementation of measures. Therefore, this might be another leverage point for policies: *Promoting actors able to offer one-stop solutions* including consulting, implementation know-how and the necessary contacts to providers. Organizational effort was found to be a motivational barrier especially for large enterprises. The second highest ranking was for difficulties in technical/ organizational circumstances (Table III-4). This cannot be linked to specific company characteristics (Table III-5), so we assume that all types of companies could benefit from offers that identify the best EE options and implement them without the work effort of the company's own employees, i.e. some kind of outsourcing of the energy efficiency issue, especially given that energy is usually more of a necessity and not the main priority of a company.

There are companies' characteristics that are related to specific barriers and the kind of implemented EEMs. Regarding barriers, especially the ways of decision making and company size play a role. A differentiation between SME and LE does make sense, but companies need to be considered in more dimensions than just size. The group of SME is more heterogeneous than LE and are different from LE, not being "like LE, just smaller". Regarding EEMs, a *self assessment tool* for companies based on those attributes could constitute a compromise between finding much individual information on each company before acting and too general instruments. An example where knowledge about energy efficiency finance related business opportunities is provided, is the De-risking Energy Efficiency Platform (DEEP). It was developed by the Energy Efficiency Financial Institutions Group (EEFIG, 2017) and the data from the LEEN are also part of it.

Larger enterprises usually implement more EEMs (due to bigger budgets, a dedicated energy manager, larger scaled technologies to implement measures on or a higher awareness of their profitable measures). Some recommendations can be made regarding specific measures related to companies' characteristics and barriers, based on the higher probability of implementation in specific groups of companies. For example, ventilation and air-conditioning measures might be more appropriate for larger companies, even if energy intensity is low. The utilization of waste heat or (provided that they are indicated) measures on the building envelope also seem applicable to companies with lower energy intensities. Measures concerning motors and pumps can apparently be conducted with lower organizational effort. Measures on the production of heat and distribution of heat, cooling and compressed air are more often implemented by LE, but fall under the group of generally favoured measures for SME as well, together with measures on lighting, motors and pumps.

Table III-9 delivers some approaches beyond the typical regulative, informative and economic measures and indicates how to challenge problem areas in implementation.

Table III-9: Approaches to react on individual barriers and characteristics of companies regarding EEMs

Problem area for EEMs	**Influencing factors and indicators**	**Proposed approach**
Lack of information/ mistrust in benefits of measures	Hesitation to invest/ implement despite availability of profitable measures, avoidance of changes,	Models of pioneer companies, information on implementation process (beyond recommendation of measures)
EEMs have low priority lack of time, expertise and resources	Process of searching, getting informed and implementing is too effortful, transaction costs are too high, people in charge are overstrained	Offer one-stop-solutions for companies to outsource the process
Profitable measures neglected due to financial issues	Inappropriate payback periods are applied, non-financial benefits are put into the rear, decisions about expenses cannot be made autonomous, no possibilities for financing	Reasons should be differentiated. Depending on them: Incentivize consideration of longer payback periods, demonstrate multiple benefits, implement low-level-measures which can be decided within the company, provide funds or loans.
Heterogeneity between companies within one sector, no general recommendations can be given	More influencing factors on implementation of measures than sector or companies' size	Promote individual audit; esp. for SME: develop self assessment tool for recommendations on measures fitting to company-type
Motivational barriers	Predominantly in LE implementation is stated difficult despite availability of profitable measures	Measures should directly affect as few employees as possible, shift of decision criteria from financial aspects to effort, support implementation process

Tailoring measures means reacting to individual barriers and characteristics that influence decisions and opportunities. This paper shows that size is not the only criterion to differentiate enterprises regarding EEMs and that barriers cannot be generalized to sectors. Barriers often occur on multiple levels and for more than one reason. These specific reasons need to be considered to ward off those barriers. In order to give tailored recommendations for appropriate measures without conducting individual audits, they need to be refined regarding company characteristics – besides size and sector e.g. level of experience, decision making, organisational circumstances, motivational issues and energy intensity.

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Chapter IV

Setting course for demand response in the service sector

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Abstract

The increasing share of renewable energies in electricity generation is within the scope of the energy transition. Among other things, this will lead to a more volatile generation of electricity. A more flexible energy demand could contribute to handling the resulting challenges in electricity grid management. The service sector is one of the target groups for utilising flexible demand, also called demand response (DR). Supermarkets, hotels and office buildings can be found in regions throughout Germany. This could be an advantage regarding the compensation of grid instability in any region, compared to more locally focussed industrial enterprises. First estimations point out considerable unused DR potentials for the service sector. However, currently there is less knowledge about flexibility options in the service sector than in industry. Moreover, market barriers such as a missing adequate regulatory framework offering attractive incentives prevent that the potentials are tapped.

Therefore, in this paper, we first analyse survey data from 1.000 companies of the service sector in Germany to identify subsectors that have a high share of flexible cross-sectoral technologies in electricity consumption. Data indicates that the subsectors trade, restaurants and hotels as well as office-like buildings are the most promising subsectors of the service sector regarding demand response potential, since they have a high stock in flexible cooling appliances, air conditioning and ventilation. In a second step, we conducted stakeholder interviews, to find specific barriers, drivers and possible starting points in each of the identified subsectors. Still unapt or missing regulatory framework conditions, low profitability and a lack of knowledge regarding flexibility potentials and marketing mechanisms seem to be the main barriers. However, framework conditions promoting demand response measures are improving, e.g. technical standards and latest regulatory revisions. This indicates that in order to tap the existing demand response potentials in the service sector, the value of flexibility in demand needs to be appreciated, e.g. by facilitating market participation or by creating offers resp. rewarding the enterprises' flexibility of demand. In addition, addressing demand response issues in already existing policy measures such as energy audits could raise awareness and knowledge.

1 Introduction

The German electric energy system is currently undergoing a major transformation and will most likely continue to do so until 2050. By 2050 the contribution of renewable energy sources shall have a share of 80 % in the electric energy mix (Deutscher Bundestag, 2010). Amongst the largest contributors will be wind and solar power. Due to the high dependency on weather conditions, electricity generation from those sources is volatile and hard to predict. As a consequence, major challenges for the German electricity grid regarding system stability and security of supply will arise.

System operators dispose of multiple measures to address the issues caused by volatile energy resources. The currently most common measures are redispatching conventional power plants or to use balancing energy to offset the volatile generation from renewable energy sources. This does, however, result in higher costs for the operators of those power plants (Deutsche Energie Agentur (dena), 2015).

As the final goals are maintaining security of supply and at the same time having a highly efficient energy system, other options might become increasingly important in the future. One of those options is to adjust demand to the volatile electricity generation. This concept is usually called "Demand Side Management"(DSM). However, the term DSM is not always used consistently. Some concepts treat demand response or loadshift as synonymous. Other definitions use DSM-measures as a hypernym for related concepts, subsuming changes in the amount of energy use as well as changes in the time of use, and thereby summarize approaches to operate energy demand (Cowart et al., 2003; Palenski and Dietrich, 2011; IEA, 2016). Following the latter, we refer to DSM as changes of the demand side of markets. The aim is to achieve a more efficient energy system (e.g. an overall lower need of electric energy production and thus also less adjustment by conventional power plants). We use the term demand response (DR) as one mechanism with which a single consumer can contribute to DSM by changing his consumption pattern "behind the meter". It comprises changes in his consumption behaviour as well as the different use of technologies, i.e. the adjustment or shifting of loads of flexible electric applications at certain points of time. This means, DR is included in the term DSM and deals mostly with short-term adjustments in consumption.

The overall aim in DR or DSM for the energy system is to eventually avoid conventional balancing power plants and to support grid stability. The future substitution of conventional balancing power plants by DR balancing options is attractive in several ways: Avoiding power plants for balancing power additionally contributes to decreasing CO_2 emissions by substituting fossil fuels (dena, 2010). Moreover, DR could be a more cost-efficient option to deal with the intermittency of renewable energies than storage options or reinforcing the grid infrastructure.

In order to evaluate the consumers' DR potential, four different types of potentials should be distinguished (Rudolph and Wagner, 1997; von Roon and Grobmaier, 2010) – the *theoretical*, the *technical*, the *economic* and the *practical potential*. The *theoretical potential* can be considered as the most general potential, as it describes the summed load of all applications with eligible technologies for DR and therefore gives an upper limit for the DR potential. The *technical potential* considers additionally technical and operational restrictions reducing the available DR potential of the applications which includes, amongst others, load profiles, ramp up/down times, partial load restrictions or security regulations. In contrast to the technical potential the *economic potential* calculates the potential taking the economic viability of the DR options for the applications into account, considering investments, operational expenses and possible financial profits. The *practical potential* is highly dependent on subjective opinions and barriers like perceptive restrictions, knowledge and complexity of decision-making and therefore is also difficult to quantify in terms of the actual load available for DR compared to the other mentioned potentials.

1.1 Literature overview and research questions

In Europe, mainly the industrial sector has been in the scope of research on DR. Gils (2014) found in his research an average theoretical potential of 93 GW for load reduction across all sectors (industrial, tertiary, private) in Europe with main contributors being energy intensive industries. In the case of Germany, existing studies attribute a substantial technical potential to the energy intensive sector (see Table IV-1), mainly due to the energy intensity of the sector-specific processes (VDE, 2012; Klobasa, 2013). The main advantage of industrial DR processes is the ease of system integration and accessibility due to a high and easy to predict load demand of the individual processes (VDE, 2012). Yet, a large share of the industrial potential lies in within the production processes of the enterprises, which can be problematic to be modified (dena, 2010; VDE, 2012; Focken, 2011; Klobasa, 2013). Especially the fear of loss in product quality, disruption of continuous production processes and resulting financial losses are perceived as barriers (Olsthoorn et al., 2015). However, other studies additionally estimate that industrial cross-sectional technologies, such as compressed air, ventilation, pumps and cooling, have a high economic DR potential (2.4 GW of 3.5 GW total economic potential; dena, 2010). This increases the need of a potential exploitation of DR in other sectors.

Yet, since the tertiary/ service sector contributes to 29% to the overall electricity consumption in Germany (2013), it can possibly take an important role for DR (AGEB, 2015). There are already some studies which identify viable technologies (Stadler, 2005; Gils, 2014) and estimate theoretical, technical and economic potentials via modelling (Klobasa, 2007; VDE, 2012; dena, 2010). Those studies give an idea of the extent of the DR-potential in the service sector (see Table IV-1). In particular, dena (2010) shows that the tertiary sector can contribute a significant amount towards the future DR potential if the right economic incentives are set (dena, 2010).

Table IV-1: Estimated demand response potentials by different studies.

Study	**Estimated Maximum Potential**		**Potential type**	**Proj. Years/ Base**	**Notes**	**Sector**
	Peak power (GW)	Flexible energy (TWh)				
VDE, 2012	4.5		Technical	2010-2030	Energy intensive industries	Industry
Dena, 2010	3.5	12.2	Ecomomic	2020	Energy intensive industries and cross-sectional technologies	Industry
Klobasa, 2007	10.3	6.3	Theoretical	2004	Cross-sectional technologies	Service
VDE, 2012	1.4 -1.8	5 -9.7	Technical	2010-2030	Based on standard load profiles and 500,000 inhabitant model city	Service
Dena, 2010	1.6	5.7	Economic	2020	Roll-out with financial incentives	Service

According to Stadler (2005), Klobasa (2007) or Grein and Pehnt (2011) the most promising and easy accessible technological appliance in the service sector is cold storage in the food-trading sector. Research has been done to address system integration and marketability (e.g. Grein et al., 2009; Focken et al., 2011). Other research focussed on potential barriers and enablers influencing the integration of DR into the energy system. A British study highlights the large expected potentials in the non-domestic sector (Element Energy Limited, 2012) and found that the fear of negative impacts on service levels and missing financial incentives are two of the main barriers. These are comparable barriers as in industry, but compared to the industrial sector, there is probably greater lack of awareness of potentials and options. Additionally, arrangements for DR are complex and offers to access the market are missing. In Germany, many of the barriers to DR are on the regulatory side (Jahn and Gottstein, 2013). Regarding enablers Goldman et al. (2007) and Fin and Fitzpatrick (2014) analysed alternative electricity tariff models (e.g. time-of-use, critical peak pricing). In addition, education, information and case studies are perceived as propelling measures to promote DR (Element Energy Limited, 2012).

The USA are often seen as exemplary for the use of DR, because of their years of experience in implementations. California is a leader in automating DR, especially in reducing peak demand. Kiliccote et al. (2010) provide a summary of participation and DR strategies for commercial buildings to reduce peak demand (mainly retail stores). Peak reductions between 5 and 15 % are reported with an average of 13%. The Western University of Ontario, Canada, achieves 20% of load shaving during the summer peaks, which achieved 2

million dollar savings over a two year period, i.e. getting more back than invested in. The campus community is involved in taking actions and the energy use of any building across campus can be monitored. In early 2015, the Western University received the Environmental Award of Excellence from the Minister of Environment and Climate Change (Western University, 2017).

The California Public Utilities Commission informs on its webpage about DR programmes and research findings. Pacific Gas & Electric (PG&E), southern California Edison (SCE) and San Diego Gas and Electric Company (SDG&E) each publish monthly reports on their DR actions and provide detailed information on their programmes and how to participate. Case studies highlighting companies that have saved on energy and costs utilizing automated DR (auto-DR) are documented, too.

Bayer (2014) argues that studies on DR from USA cannot be seen as exemplary or transferrable for Germany in general. The potential of the sectors of shiftable resp. sheddable loads is overestimated due to different definitions of terms and not least because the use of emergency generators and efficiency measures are included. Additionally, the switching of loads is only meant as emergency procedure, not as regular loadshift to adjust to the generation of wind and PV electricity. Thus, no recommendations for the German operating reserve market can be given due to the different purposes of the markets and regulations. Anyway, case studies and their lessons learned can indicate the functioning of technical requirements and deliver experiences with organisational constraints.

But even though studies on DR in the service sector do exist, practical and specific knowledge about DR integration of processes used in the service sector remains scarce. Unlike the industrial sector, the trade and service sector has been less explored regarding DR potential and there is less practical experience in conducting DR measures. Specific conditions and resulting barriers, as well as viable starting points for German companies of this sector are mostly unknown. The main issues in this sector are the lack of extensive comparable data to evaluate DR and the heterogeneity of the operational fields. However, currently it is still not clear how to design these incentives to exploit the DR potential in the service sector.

Therefore, our study focuses on two main issues: First, the identification of the most promising subsectors of the service sector depending on electricity consumption and availability and the share of consumption of flexible technologies. Second, the analysis of the practicability of using the identified technologies in the selected subsectors by taking the enterprises' perspective into account. The aim is to determine specific starting points for measures and which requirements need to be given.

Our research focuses on the following questions:

- *Which technologies and subsectors of the service and trade sector seem most promising for demand response?*

In case of a promising sector:

- *Which conditions and barriers affect the realisation of the potential?*
- *What can be done to tap them?*

The final goal of this study is to identify and characterize those promising sectors and find the needed conditions, regulatory and non-regulatory, in order to gain access to the available DR potential.

2 Regulatory framework and market conditions for DR in Germany

2.1 Overview of regulatory and market instruments

The DR potentials are evaluated, taking the regulatory and market conditions in Germany into account. In Germany, flexible loads can be traded on the balancing as well as on the spot market. Moreover, transmission system operator and DR providers can reach an agreement on using the loads for congestion management under the Sheddable Load Act (Abschaltbare Lasten Verordnung – AbLaV, 2016). Moreover, the Electricity Access Charge Ordiance (StromNEV, 2005) currently constitutes a regulatory barrier for the use of the DR potential. In the following, those marketing potentials and regulatory barriers are briefly discussed.

2.1.1 Marketing of flexible loads on balancing and spot markets

Power plants as well as flexible consumer loads have to prequalify in order to access the balancing markets. The prequalification guarantees that they meet the minimum technical market requirements. In Germany, the balancing market is split into three submarkets, the primary, secondary and minutes reserve market. In the last few years, regulations have been adapted to facilitate market participation for smaller loads. Among other things, lower minimum bids and shorter bidding cycles have been introduced (cf. SEDC, 2015).

In the primary reserve market (or frequency containment reserve market) power plants and consumer loads which are available within 30 seconds can participate. The minimum bid size amounts to 1 MW. In the secondary reserve market (or automated frequency restoration reserve market) loads have to be available within 5 minutes. The minimum bid size amounts to 5 MW. To participate in the minutes reserve market (or manual frequency

restoration reserve market) loads have to be available within 15 minutes. The minimum bid size in this market is 5 MW as well.

However, in the secondary as well as in the minutes reserve market smaller loads can be pooled, e.g. by third party market players such as aggregators. Currently, the main barrier to balancing market participation of DR is that there are no standardized processes and contracts for the settlements between aggregators, balancing group managers and suppliers. Yet, the German regulatory agency Bundesnetzagentur (BNetzA) and other relevant stakeholders are currently discussing further standardization (the "aggregator-model"), which suggests a standardized process, in particular for quantity balancing and financial compensation between aggregators and balancing group managers (cf. BNetzA, 2016).

On the spotmarket, too, flexible consumer loads can either participate directly or via aggregators with the same contractual difficulties as for the operative reserve market (cf. SEDC, 2015). Moreover, indirect participation is possible by negotiating flexible tariffs with the energy suppliers, who use the demand side flexibility within their portfolio optimisation. However, profits from participation in balancing as well as spot markets are currently rather low, e.g. because of overcapacities and low prices for primary energy (Eßer et al., 2016).

2.1.2 The Sheddable Loads Act

The AbLaV was issued in 2012 and revised in 2016. It allows transmission system operators to advertise their needs for sheddable loads for balancing or redispatch. In total they tender 750 MW of immediately sheddable loads (reaction time within seconds) as well as of quickly available loads (max. 15 minutes reaction time). The revision in 2016 was made, because participation was rather limited in the first four years after implementation. To increase participation, the size of minimum bids was reduced from 50 MW to 5 MW in 2016. Moreover, pooling of smaller loads and the participation of flexibility providers connected to the medium voltage grid were facilitated. Consequently the AbLAV is now accessible for smaller loads, e.g. from the service sector.

2.1.3 Restrictions for the marketing of DR through the Electricity Access Charge Ordinance

According to StromNEV (2005) electricity consumers can profit from lower grid fees in case of so-called special types of grid use. This is the case if either their electricity consumption exceeds 10 GWh within at least 7000 utilization hours (intense grid use), or if their maximum electricity purchase lies outside the high-load periods defined by the network operator (atypical grid use) (StromNEV§19, sec. 1 and 2). Since DR can result in higher peak loads or considerable load reductions, the DR supplier risks losing his grid fee privileges. Since this loss would be larger than possible avails through the marketing of DR, DR is unattractive for consumers currently benefitting from §19 StromNEV.

2.2 Status quo of demand response in the service sector

In particular, large, energy intense enterprises or third party players participate in the above mentioned markets for flexible loads. In the balancing market, only 62 providers (regelleistung.net, 2016) are prequalified with 2500 MW of flexible consumer loads. Only 25 MW of consumer loads actually participate in the secondary balancing reserve market, while 160 MW participate in the minute reserve market. Most of the enterprises participating are from the industrial sector, e. g. aluminium or steel, operators of operating reserve pools and virtual power plants with decentralized generating capacities for consumer loads. Companies from the service sector have not been participating in this market so far (Weißbach, 2015).

This has several reasons: First, many flexible consumer loads from the service sector do not fulfil the preconditions for participation, such as minimum bid sizes. Pooling is an option, but regarding the current conditions, pooling of smaller loads is not beneficial of aggregators or DR-service providers (Eßer et al., 2016). As described in the section above, the effort resulting from the lack of standardization is too high compared to possible rewards. Thus, the balancing markets are not very attractive for flexible consumer loads from the service sector.

However, some large enterprises from this sector have recently started to participate in the spotmarket and have tried to minimize the energy costs using DR. Other DR-options are the minimization of peak loads or the classification for devices with atypical grid loads which results in lower grid fees for the customer.

Until 2016, the AbLaV only addressed larger consumer loads, which resulted in not more than seven contracts under that regulation (regelleistung.net, 2017). In interviews with the representative stakeholders of subsectors, the AbLAV was therefore repeatedly called to be “a hidden subsidy of energy-intense industry” which indirectly excludes companies from other sectors from that option. Since the revision of the AbLaV opens the instrument for smaller sheddable loads, a participation of loads from the service sector might now be more attractive.

3 Methodological approach

Our methodological approach consists of two parts: the analyses of quantitative survey data and qualitative stakeholder interviews. Concerning survey data, we reanalyse data from a study on "Energy consumption of the tertiary sector (trade, commerce and services) in Germany" (Schlomann et al., 2015). The study contained a survey of approximately two thousand enterprises in the tertiary sector, including the typical subgroups: trade, commerce and services plus agriculture, small manufacturing enterprises and military.This allows for detailed analyses of the relevant subsectors. The distinction of the tertiary sector in industry (affecting esp. the distinction between manufacturing enterprises and industry) is done in analogy to the official energy balances of Germany (AGEB, 2014). As the focus is on energy consumption, the subsectors were composed based on structural similarity, grouping enterprises together which do not necessarily belong to the same NACE-codes (Statistical Classification of Economic Activities in the European Community; e.g. office-like enterprises including a large variety of objects of the enterprises on comparable structure). The survey was conducted in 2014 and contained questions about companies' characteristics and other energy-related items (for more details cp. Schlomann et al., 2015). In our new analysis on the DR potential, we focus on data regarding energy consumption of subsectors, availability of technologies with flexibility potential and the energy balances for applications. The relevance of the share of one subsector compared to the whole sector and the availability and share of demand which is caused by flexible technologies is our decision criteria indicating promising subsectors for DR.

Having identified the most important subsectors, we contribute qualitative data of interviews with stakeholders to examine framework conditions, possible barriers and practical starting points to tap the DR potential. The decision to use qualitative data was made, because our interest lay especially in the sensitivities of each subsector and the nuts-and-bolts of feasibility. Those can hardly be expressed in numbers for loads or energy, but strongly affect the actual, practical potential and should therefore necessarily be taken into account for practical issues.

The selection of stakeholders and main issues of the interviews were discussed within our research group. We interviewed at least one stakeholder for each of the identified promising subsectors and representatives for more super ordinate stakeholders like aggregators, consultants or energy service providers (Table IV-2).

Our interviewed stakeholders represent a larger number of enterprises for our selected subsectors. It was not our aim to ascertain a statistical relevant number of interviews, but to interview the relevant representatives for our topic. Thus, we received individual perspectives of the topic. However, those perspectives converged into a coherent overview of the situation for DR in the service sector, giving us the basis for further in-depth studies of promising subsectors for DR.

Table IV-2: Selected stakeholders for the interviews

Scope	Stakeholder	Organisation of interviewee
Superordinate	Aggregator	EnerNOC
	Energy services	Next Kraftwerke (Virtual power plant operator) Beegy (energy service provider) EnBW (energy provider south Germany) Tübingen SW (Local communal energy provider) EnQS (consulting, public services on energy management) Transnet BW (TSO south-west Germany)
	Technology suppliers	Sicotronic (load management solutions for hotels/ restaurants)
	Regulator	BNetzA (Bundesnetzagentur, German regulator for electricity grids/ networks)
Subsectors	Retail trade	HDE (German association of retail trade enterprises) EHI (Research institute for retail trade)
	Hotels/ restaurants	Adelphi (project management; managing energy section for the German hotel and gastronomy association DEHOGA)
	Office-like enterprises	PWC (consulting enterprise with own energy management section) Vollack (project management and planning office for builders)

The interview guideline consisted of three main parts: an introductory part where the aim of the study was explained and the interviewee introduced himself, a second part with questions about the availability of DR options or previous related experiences and a last part focusing on barriers and drivers influencing the chances to implement DR measures. We designed the guideline in a semi-structured way to give the interviewees the chance to add enhancing comments and issues we did possibly not anticipate while designing the survey. All calls were intended more as discussions than interrogations to gain deeper insights into points influencing the interviewee's attitude and way of decision making. The interviews were conducted via telephone in the second half of 2016 and usually took about one hour. The analysis of the interview data was done using the recordings by transcribing them and categorizing the statements using a classification scheme for the main issues: electricity consumption and energy management, flexible technologies and options for DR, drivers and barriers towards DR. For our evaluation, we distinguished between general and sector-specific findings.

4 Results

4.1 Identifying flexible technologies and promising subsectors in the service sector based on survey data

We used two criteria to select our subsectors of interest for DR: energy consumption of the sector and the availability of flexible technologies. We first introduce our selection of flexible technologies based on prior research. Then we analyse the balances for electricity consumption in the different subsectors to identify the most consuming ones and those with large shares of flexible demand.

Identifying potentially flexible technologies within the subsectors

Regarding the technical potential, we consider especially appliances, which technically allow a certain flexibility of demand within the chosen subsectors. Table IV-3 shows our set of flexible technologies, relying mainly on compilations of flexible technologies of Klobasa (2007), VDE (2012) and Gils (2014). We assessed those and only regarded electric appliances with a significant share in total load or consumption and whose load can be flexibly adjusted to some degree without influencing the core of the enterprises' business. Thus, we finally arrived at a set of technologies describing essentially appliances of cooling, heating and air conditioning (Table IV-3).

Table IV-3: Flexible appliances in the service sector

Type of appliance	**Flexible appliance**	**Containing category from energy balances for appliances** (cp. Table IV-4)
Cooling	cold storage	Process cold
	retail cooling	Process cold
	hotel/restaurant cooling	Process cold
Air conditioning (AC) /Ventilation	ventilation	Mechanical power
	air conditioner	Air conditioning
Warm water	electric water heating	Hot water
Room heating	storage heater	Space heating
	heat pump/ recirculation pump	Space heating

Identifying promising subsectors

To evaluate the most appropriate subsectors for DR, we then analyse the energy consumption of each subsector (Table IV-4) using the data assembled in the survey (Schlomann et al., 2015). The numbers on the electricity consumption of 2013 show that the subsectors office-like enterprises, retail trade and hotels, restaurants and homes consume by far the most electricity. Considering consumed electrical energy as an indicator,

this suggests a high theoretical DR potential for those sectors. Together they account for more than 50 % of total electric energy consumption of the tertiary sector (70.5 TWh/a, about 14% of Germany's total electricity consumption), while the rest is split up into smaller shares over a larger number of structurally different subsectors. This means in effect, that covering those three subsectors concurrently involves the largest parts of the sector. Having a more homogenous group of enterprises, sector-typical standards can be established more easily, compared to approaching more compartmentalized sectors.

Table IV-4: Electricity consumption in tertiary sectors (including service) 2013 (Schlomann et al., 2015)

2013 Electricity consumption (TWh/a)	Lighting	Mech. power	*Hot water*	Other process heat	*Process cold*	*AC*	ICT	*Space heating*	**Total**	**Sum of relevant shares**
Construction industry	1.8	0.7	*0.5*	0.1	*0.0*	*0.1*	0.3	*0.3*	3.8	0.9
Office-like enterprises	13.3	1.3	*0.9*	0.4	*0.7*	*0.9*	10.9	*1.1*	29.5	3.6
Small manufacturing enterprises	1.5	1.6	*0.2*	0.0	*0.0*	*0.0*	0.4	*0.2*	3.9	0.4
Retail trade	11.0	2.1	*0.7*	0.6	*4.2*	*0.5*	1.9	*1.4*	22.5	6.8
Hospitals	1.2	1.7	*0.3*	1.7	*0.1*	*0.3*	0.6	*0.1*	6.1	0.8
Schools	2.9	0.1	*0.1*	0.1	*0.0*	*0.0*	0.4	*0.1*	3.9	0.3
Baths	0.2	1.1	*0.0*	0.0	*0.0*	*0.0*	0.0	*0.0*	1.4	0.0
Hotels, restaurants, homes	5.3	4.8	*1.3*	2.1	*2.5*	*0.2*	1.0	*1.4*	18.5	5.4
Foodstuff (bakers, butchers, other)	0.2	0.1	*0.0*	0.4	*0.1*	*0.0*	0.0	*0.0*	0.9	0.3
Laundries	0.1	0.0	*0.0*	0.2	*0.0*	*0.0*	0.0	*0.0*	0.3	0.0
Agriculture	1.1	1.8	*0.5*	0.0	*0.1*	*0.4*	0.2	*0.2*	4.3	1.3
Horticulture	0.2	0.0	*0.1*	0.0	*0.0*	*0.0*	0.0	*0.0*	0.4	0.1
Airports	0.5	0.4	*0.1*	0.1	*0.0*	*0.1*	0.1	*0.1*	1.3	0.3
Textile, clothing, leather	0.6	0.1	*0.0*	0.0	*0.0*	*0.0*	0.2	*0.2*	1.1	0.2
Remaining groups*	1.1	7.9	*0.1*	0.4	*2.9*	*0.0*	4.1	*0.2*	16.8	3.3
Other	5.8	8.6	*0.2*	0.2	*0.1*	*0.1*	1.0	*0.0*	15.9	0.4
Total	46.7	32.5	*5.0*	6.2	*11.0*	*2.7*	21.1	*5.4*	130.6	24.1

*: not covered by the questionnaire

The last column of Table IV-4 "sum of relevant shares" is the sum of the consumption of the flexible appliances (cp. Table IV-3 and highlighted in italics), indicating the available theoretical flexibility potential. This value needs to be revised downwards, as not the

whole consumption of an appliance is technically flexible. However, the numbers allow comparisons and show that regarding flexible technologies, our selected sectors still point out the largest potential compared to other subsectors. The findings are in line with Klobasa (2007): He argues that the most interesting appliances allowing DR are found predominantly in those sectors, viz. cooling, heating and air conditioning due to their function as energy storage.
The next sections focus on practicability of DR in our selected sectors, taking the stakeholder interviews into account.

4.2 Evaluating framework conditions, barriers and options to tap the DR potential in the service sector

The basis of our evaluation, which considers practical issues when implementing DR measures are the interviews conducted with stakeholders for DR in the service sector. If appropriate, findings from literature are added. We focus on the specific issues of each subsector after giving an overview of general findings for all considered subsectors.

4.2.1 Office-like enterprises

Our interviewees stated that for office-like businesses, DR is a non-issue so far. However, they also see potential for DR, e.g. in AC and ventilation or measures like using the building as energy storage. In that case, the building would for example be cooled down already over night in the summer time if overcapacities of energy are available; the energy is thereby stored in concrete ceilings. Habits of staff might interfere with DR measures, e.g. if AC is used for DR, people opening windows disturb the order of the system and leads to a restricted predictability of the loads. The interviewees especially pointed out that measures must not impair the comfort of the staff, because the quality of their work could suffer. In a way, they see the same problem as the manufacturing industry here, fearing a loss of product quality caused by DR measures. In line with their former experiences from energy efficiency issues, they still expect that low hanging fruits for DR can be reaped without jeopardizing the acceptance of the staff. Knowledge and required technology seems to be easily accessible. But also awareness and the support of experts for the implementation of measures will be needed to assure the necessary trust and acceptance. In larger, modern office buildings, control technology is already available but often untapped for the purpose of optimizing energy consumption (efficiency as well as DR). In other cases, upgrades and retrofits to enable DR are considered as a possibility to implement DR-measures, but the required investments make profitability a relevant barrier. However, there are fewer intrinsic incentives for DR than for energy efficiency measures. Thus, enterprises need to be approached by aggregators or suppliers with offers valuing their demand flexibility. The interviewees did not expect that the business owners in the offices would agree to hand over the control of appliances to somewhere outside the building. Thus, a starting point is seen in individual contracts with energy suppliers so that the dialogue and interaction are given and mutual appreciation can be preserved.

Offices need to be seen as a special case in comparison to our other selected subsectors, because it is no subsector in the strict sense. That is why there are no associations or other structures that organize those businesses to spread knowledge or to raise suchlike issues. Instead, flagship-projects for DR might function to raise awareness and prove feasibility.

4.2.2 Retail trade

DR-potential in the trade sector as a whole lies in ventilation and AC. Regarding food-retail, a larger potential can be attributed to cooling and cold storage appliances, where also a large share in electricity consumption is caused. Additionally, unique technologies for specific kinds of markets were mentioned, such as baking machines for baked goods in self-service markets or TVs in hifi-stores. In addition, the use of CHP and emergency generators was suggested as possible appliances for DR. Since in the trade-sector (esp. food), electricity costs are an important issue and the market potential of DR has been recognised, the usage of cooling and AC for DR is being evaluated among representatives of the subsector. Like this, DR options seem to be most actively taken into consideration within the trade sector compared to the other subsectors. Nevertheless, they feel overlooked and discriminated against by regulatory conditions, especially compared to the industry sector. Until the revision of the AbLaV, taking advantage of that regulation was apparently meant for energy-intense industry enterprises. Yet, pooling of loads is still difficult.

In practice, using cooling appliances for DR in retail stores is difficult, because it has to involve customer behaviour: If appliances are switched off for DR purposes, a constant temperature still has to be guaranteed to keep a constant cooling chain for the foodstuff. However, warm air is let into the cooling devices if customers open them to take out frozen food. This also means to take away the medium for stored energy (cold, in this case) which additionally decreases the profit margin of the frozen food.

Concerning AC, some companies try to combine and control flexible loads of several stores of a corporate chain. Generally, corporate chains are seen as favourable pioneers: only the headquarter needs to be convinced, communication is easier as the single enterprises already have connected structures, purchases are centralized and measures could be rolled out for larger number of enterprises in one go. Above that, larger chains or enterprises often have regular phases of refurbishment or renovation when suchlike measures could be implemented and installation of control systems or change of appliances can be arranged. Monitoring systems and decentralized control systems are common, esp. in larger stores. However, there are yet few centralized automatic control systems, since data security is an issue there. Regarding the existing competition between the different corporate chains, pooling of loads over branches of one chain is regarded to be much easier than if rival companies are involved. Therefore, there might be inhibition thresholds towards other third parties as aggregators. Considering that most enterprises of the sector are branch stores of larger chains, the competition could be used to raise pressure to participate, e.g. if a flagship-project has been successful and raised the interest in DR. Yet, our interviewees assume, that the courage to run the risk is possibly missing.

4.2.3 Hotels, restaurants and homes

Enterprises from this sector usually have AC, ventilation and refrigerators as well as cooling devices available which can be used for DR. Above all, kitchens have high loads and electricity consumption, especially those including heating processes. Hence, enterprises with large kitchens usually have special contracts with their energy supplier. If they want to save costs by keeping that load under a defined level, they are equipped with an intelligent load management system controlling their kitchen devices. According to an example given by our interviewed technology supplier, large kitchens can have approximately 700 kW of connected load which causes peaks of about 500 kW. Using controlling systems, appliances can be rescheduled to reduce peak load to 300kW. Accordingly, users of such controlling systems are already involved in using the flexibility of their energy consumption by internally avoiding peak loads. For that purpose, several appliances are coordinated and separately delayed to keep the absolute load low. For some appliances, only heating processes are delayed, while the appliance itself keeps running. For other DR purposes, other timings of appliances or control of single appliances would technically also be possible.
A DIN standard has been developed, so theoretically all appliances with heat output could be taken into account. However, load shedding (in the sense of switching off appliances for a while) is not appropriate for cooking devices in kitchens, because when guests arrive and meals have to be prepared, the devices have to be ready on demand. Yet, devices like plate warmers or heating cabinets can be switched off for time intervals. Depending on the complexity and number of appliances, costs for those intelligent load management installations amount to a four to five-digit euro range. Yet, according to our interviewed technology supplier, they usually pay off after a few years. An additional use of those management systems for DR applications could further decrease the payback period.

Other appliances could work for DR even with gains in comfort: If ventilation can be controlled and e.g. down-regulated over night, noise is reduced for guests in their hotel rooms and energy is saved. An automated regulation of AC can be used for DR without losses in comfort when it is regulated within the target range of temperatures. The control of the appliance under these conditions is rather acceptable from outside of the enterprise. In that case, too, trust is a relevant issue.

The following Table IV-5 summarizes the key findings for each of our considered subsectors:

Table IV-5: Summary of interview results

	offices	**Retail trade**	**Hotels/ restaurants**
Most appropriate appliances	AC, ventilation	Ventilation, AC, cooling/ cold storage	AC, ventilation, refrigerators, kitchen devices
Drivers	"Low-hanging fruits" – untapped potentials, appliances of interest not part of core business	Cooling and AC for DR already evaluated Competition between corporate chains (competitive advantage)	High loads (esp. in kitchen) Load management common for kitchen devices in large companies Possible gains in comfort due to controlling software
Barriers	Habits/ routines of staff Fear of loss in quality No handing over of control	Feeling of discrimination against industry Customer might impede DR Competition between corporate chains (pooling)	DR may not impose routines/ comfort of customers
Starting points	Individual contracts with providers Flagship projects Modern buildings already dispose of control software for facility management	Regular phases of refurbishment Chains/ associations facilitate roll-out	Load controlling systems in kitchens

4.2.4 General findings applying for all subsectors

All interviewed stakeholders agreed with the general relevance of DR for the efficiency of the future energy system and its gains for sustainability. In respect thereof, they did not perceive conflicts between pursuing concepts of energy efficiency vs. DR, but pointed out the advantages: Regarding system level, DR with the aim that demand follows generation is seen as a way of contributing to energy efficiency. On the level of the enterprise, knowledge acquired about energy issues by dealing with energy efficiency measures and possibly installed technologies to control the demand of appliances can promote the implementation of DR. With the necessary expertise, upgrading infrastructure to be DR-ready could be done with a little more effort in the course of refurbishments or if appliances are changed anyway. Such measures can comprise multiple benefits: E.g. insulating the building means energy savings and can also go hand in hand with higher comfort and larger potentials for DR as

the building keeps temperatures better and can therefore function as energy storage. On the level of single appliances, DR can interfere with energy efficiency issues, especially if a flexible use means an appliance is operated inefficiently. Efficiency on the energy system level, however, does not necessarily mean to reduce consumption to a lower level, especially if (surplus) energy is used when it is available.

Usually appliances are replaced only in case of defect. Information is useful, because product labelling is often hard to understand, but then, the tendency to choose the well-known same as before often prevails. When making decisions, price, comfort, availability and demand usually outweigh energy efficiency aspects. Therefore optimization is usually possible, but stays unnoticed or is seen as a barrier. The issue of comfort is mentioned often by the stakeholders for subsectors but deemed overrated by other experts. In this regard, our interviewee for technology supply simply poses the question: "How long would it take you to recognise that the AC is not working properly?" Regarding barriers, preservation of quality of work and goods, financial risks of DR, data security, safety regulations and missing knowledge about DR were also mentioned.

The interviewees assume that knowledge about energy issues and the availability of control technologies for applications will increase within the next few years, which simultaneously advances options for DR: control systems for energy consumption are considered to be state of the art in modern facility management and will diffuse with newly constructed buildings. Additionally, by article 8 of the EED (energy efficiency directive), large enterprises have been obliged (and small and medium sized enterprises encouraged) to conduct mandatory energy audits over a four years cycle, starting 5th December 2015. Alternatively, a certified EMS can be approved. These actions are meant to increase the involvement of enterprises regarding energy efficiency issues and will support the generation of knowledge and the introduction of management systems.

According to the stakeholders the enterprises of the subsectors selected for our analysis usually have more experience with energy efficiency issues than with DR. Neither are there any regulatory requirements yet or the companies to provide DR, nor do service providers or energy suppliers approach the service sector with products focussing on DR. However, most companies know about their typically largest electricity consumers. Opportunities for DR are predominantly seen in larger enterprises, as only in those the load level and the electricity costs are high enough to raise awareness of this topic. Moreover, some companies already have energy management systems (EMS) available. Those companies might also have energy managers or personal capacities to organize direct participation at the spotmarket, but only if adequate profits can be expected.

To subsume, changes in regulations, energy management and technological developments can become door-openers for DR. At the moment, the existing markets for DR are still inaccessible or not profitable. To tap the existing DR-potential, offers and contracts need to be established to raise interest in these issues.

4.3 Starting points to tap the DR potential in the service sector and policy recommendations

Having evaluated promising subsectors and technologies as well as specific conditions and status quos for the subsectors, we like to derive starting points to tap the open potentials for DR as well as first policy recommendations.

Regarding regulatory conditions, there are e.g. the access charges (StromNEV) which interfere with the concept of DR. The idea of that regulation reflects that energy generation up to today is characterized by constant loads and deviations need to be compensated by balancing loads. Energy sources of the future are more volatile, which makes the ideal of constant consumption obsolete. The access charges should change according to the changed conditions and that regulation should be redesigned: offering schedulable demand flexibility should be rewarded instead of permanence. A rising share of renewable energy generation might increase the value of DR and induce more attractive prices and easy accessible markets for flexible loads.

To improve the accessibility of markets in turn, lowering minimum bids for participation has currently been done, which should go hand in hand with an easier prequalification of appliances. Involving aggregators to facilitate offering DR also for smaller providers is still complicated and standardized processes and contracting are lacking. Possible improvements are under discussion and are needed to remove the barrier of unfavourable market conditions. Concerning market design, several interviewees suggested that the AbLaV could be integrated into the operating reserve market. The AbLaV and the operating reserve market seem to have the same purpose and are working in quite a similar way, while the AbLaV seemed to be semi-opened in the past, however, due to requirements is only accessible for industrial enterprises. A contribution of electricity consumers to DR can also indirectly be fostered by electricity providers by including more flexible tariff models. A real time pricing tariff can function as a way to participate in DR on a lower level, without the barrier of minimum bids. Time-of-use tariffs can be a lighter option where flexibility can be pre-scheduled. This option would not necessarily require an external control of appliances and the tariff could be chosen with regard to the processes and consumption patterns of the enterprise.

In general, all market offers to trade flexibility have to meet the regulations. This means, that regulatory improvements have to be made before new concepts can be successfully established. Different ways of marketing flexibility besides trading loads at the balancing and spot markets could be developed, e.g. network-conductive services within agreements with the network operator. Thus, new market participants might come into play.

Regarding the current situation, existing tools and regulations could be utilized to support the use of open DR potentials. Many enterprises dispose of management software or even control devices, which could be used or upgraded for DR purposes. Hence, getting started with DR might take lower investments than expected. This especially pertains to larger

enterprises with relatively large potentials. The recast of EPBD (Energy Performance of Buildings Directive) on 30 November 2016 of the European Commission might be a necessary and logical step to integrate the readiness of buildings for DR into a regulatory framework. It introduces the "smart indicator" rating "the readiness of the building to adapt its operation to the needs of the occupant and of the grid and to improve its performance" and reinforces the use of electronic building monitoring, automation and control. As we learned from our interviews, modern control technologies for facilities are becoming increasingly common and are standard in newly constructed buildings. Even now, existing technologies are barely used for considering DR potentials, partly because enterprises see no relevance or have no experience. Field studies and practical trials could raise awareness and inspire confidence in the functioning of DR concepts. Trials like that can reduce reservations towards DR measures and their success will raise interest for further participants to get started. The service sector is usually seen as less sensitive for data security issues concerning energy consumption data than the industrial sector. This might facilitate to spread the word and publish exemplary data or evaluations from early adopters of DR measures. Information can also be delivered within the scope of energy audits, which are mandatory now for large enterprises (EED Article 8, resp. revision of EDL-G in Germany) anyway. The consultation of DR potentials could easily be integrated and does not need to be restricted to energy saving potentials when data on energy consumption is already gathered and evaluated.

5 Discussion

To identify our subsectors of interest, we used the electricity balances of appliances from the study of the tertiary sector. To define the most promising subgroups more clearly, the balances for appliances need to be on higher resolution, e.g. to differentiate between food and non-food retail trade. Using this data, we only know shares for categories of appliances, not for single types of flexible appliances. A calculation of the technical potential could be done more precisely with a bottom-up calculation based on such more detailed data.

We used energy consumption as an indicator to determine our sub-sectors of interest for the DR- potential. Other possible indicators could be peak demands to estimate the maximum of flexibility potential or load profiles to additionally take the time of availability into account.

Results regarding regulatory conditions are country-specific and therefore need to be considered individually for each country. Our results on sector specific issues and concerns related to special applications can largely be internationally transferred, because they are specific for applications or sectors, but not country-specific. Thus they can be used for practical considerations of DR potentials.

6 Conclusions and outlook

In this article, we focused on promising subsectors of the service sector and their special given situation to tap DR potentials. We based our selection of subsectors on quantitative data, while the considerations of definite starting points to tap the DR potential and opportunities for DR measures were approached by qualitative interview data. Integration of service sector's DR potential is not necessary or financially attractive at the moment, because backup power plants and DR offered by the energy intensive industries maintain the grid stability. Accordingly, our considerations are forward-looking under the premise that the stated aims of increasing shares of renewable energies will cause changes in the energy system and flexible demands will be of greater interest. First steps in regulatory changes have already been taken which will facilitate to touch the open potentials. Nevertheless, numbers are still hard to assess because prices for flexible loads under future circumstances cannot be foreseen yet. To learn more about quantified practical potentials, price sensitivity and willingness, data on a large number of enterprises has to be ascertained.

We concluded that the largest potentials for the subsectors of trade, restaurants, hotels and homes and office-like buildings are most promising. Concerning technologies, cooling appliances, air conditioning, ventilation, electrical hot water generation and room heating seem most suitable for DR-measures. All of them pertain to cross-sectoral technologies in the service sector and are especially common in our selected sectors. In our interviews with stakeholders, we found out that all of our selected subsectors see options for DR to some degree and have taken steps which conduce to tap that potential. Usually, appliances with flexibility potential or technical preconditions are already available resp. control software for facility management becomes more and more common with the modernization of buildings. Hence, it seems that in the future, lesser financial effort is needed for the necessary technical equipment to realise DR. Regarding the fulfilment of the requirements and the profitability of measures, larger enterprises are usually better qualified than smaller ones. In any case, experiences with energy efficiency issues are seen as useful to get into DR and to find measures to start with. On the other hand, acceptance issues have to be addressed. Barriers like lack of awareness, having no persons in charge, financial issues, worries about quality, loss of work or products and regulatory circumstances were mentioned. Enterprises also might not want to hand over the control over appliances to external operators.

Our next steps will include a quantitative survey in our selected sectors about DR potentials, available flexible appliances, experiences with DR, attitudes and organisational circumstances influencing DR opportunities. Furthermore, the construction of the survey will be based on the findings of this study. Hence we would like to complement and deepen our findings with quantitative data from the perspective of enterprises in line for DR. The survey is intended to deliver data for estimations of the practical potential as well as improvements of the modelling of the future energy system including DR.

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Chapter V

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

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Abstract

Solutions to integrate intermittent renewable energy sources are needed when designing future energy systems. Potentials for flexible energy demand (demand response, DR) can be found in every sector, but the focus so far has been on the energy-intensive industrial sector.

In this study we provide a comprehensive analysis of the DR potential of three most promising service-subsectors and their branches, using a transparent bottom-up approach, along with detailed survey data from a large sample size of over 1500 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 focus on cross-sectoral appliances of the service sector and apply our estimations of potentials on quantitative survey data in Germany and give an overview of the extent that the companies already engage in DR; the willingness to participate in DR; the availability of flexible appliances and the relevant barriers to DR. At the European level, the structure and share of electricity demand of the service sector is fairly comparable across countries (with differences arising from different climatic context); hence the insights derived here for the German context are in its main conclusions also relevant for the entirety of Europe. We identified the subsector "food retail" as well as companies that operate restaurants as the most promising target groups. These groups already have experiences with current DR measures and have demonstrated the highest willingness to conduct automated DR in the future. In addition, they operate a large number of flexible appliances and several companies are already using the control-technology necessary for DR. Appliances with the highest rate of acceptance for automated DR are those used for ventilation, air-conditioning and cooling. Combined, their technical potential for offices, trade and hotels/restaurants amounts to approximately 1.6 TWh in Germany. With the inclusion of all other flexible appliances in the subsectors described, 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. The most relevant barriers to DR measures are their perceived low priority and inadequate financial incentives due to the small share of energy costs. A regression analysis reveals that public image influences interest in DR measures. Thus, the image of DR and its influence on customers is perceived as an important driver and could indirectly increase the profitability of its implementation. The general willingness to implement DR in contrast, depends more on technical, financial and organisational issues. These results can support the realisation of DR potentials in the service sector to help balance future electricity loads and support grid stability. Additionally, knowledge of the barriers and drivers involved is valuable for designing policies that would incentivise companies to participate in DR measures.

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 (IEA, 2016; Palensky and Dietrich, 2011). 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 (European Commission, 2012), the European Network Codes (European Commission, 2009) and the Commission's Energy Union Communication (European Commission, 2015), DR is referred to as an important enabler of renewable integration, security of energy supply and improved market competition (SEDC, 2017). 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 (SEDC, 2017). 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 (2013) 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 (Olsthoorn et al., 2015). 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 (AGEB, 2015) 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 (Eßer et al., 2016).

When estimating flexibility potentials, theoretical, technical, economic and practical potentials are distinguished (Rudolph and Wagner, 1997; von Roon and Gobmaier, 2010). 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). 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. The practical potential describes what can actually be implemented, referring to the willingness to do so, taking existing barriers into account (Arnold and Janssen, 2016). Thus, the practical potential is usually smaller than the technical or economic potential, if no funding or subsidies exist. 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. Table V-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 V-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 (2010)	3.5	12.2	2020	Energy-intensive industries	Industry
Klobasa (2007)	2.8	1.3	2005	Industrial sectors and cross-sectoral appliances (esp. VAC)	Industry
VDE (2012)	4.5	0.077	2010-2030	Production processes in energy-intensive industries (alu., steel, glass, paper, cement, chemical …)	Industry
Dena (2010)	1.4	5.7	2020	Especially cross-sectoral appliances (air conditioning, ventilation, cooling, water/ room heating), financially incentivized	Service & Trade
Klobasa (2007)	10.3	6.3	2004	VAC, cooling, night-storage and water heating, server	Service & Trade
VDE (2012)	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 (Eßer et al., 2016). So far, companies from the service sector are not represented in these markets (Weißbach, 2015). Accordingly, the share of companies that have not yet addressed DR issues is distinctly higher than in the industrial sector (see Table V-4): 42% in the service sector, vs. 26% in industry; Agora, 2013). 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" (SEDC, 2017). The share of companies from the service sector participating in load management schemes is higher in countries with a more favourable regulatory environment (Reiter et al., 2018). 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 (Eßer et al., 2016). 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 (AbLaV, 2016) 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 (Wohlfarth et al., 2018). 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. 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 to our knowledge not yet been provided at all. The USA is often referred to as far developed in DR experiences, but it also needs to be said that neither the grid situation nor the requirements of flexibility or regulatory situation is comparable to Germany; usually also definitions of terms of flexible loads differ (Bayer, 2014). Studies from the US dealt with the estimations of bottom-up flexibility potentials by

calculating the sums of flexible shares of appliances, also considering aspects of acceptability (Starke et al., 2013; Olsen et al., 2013), 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).

To evaluate options to support the energy transition, in this study we therefore provide a comprehensive analysis of the flexible demand potentials in the service sector. In previous work, we already identified promising subsectors of the tertiary sector and their available technologies and appliances using qualitative methods (Wohlfarth et al., 2018). 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 (Schlomann et al., 2015). 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 (2007), VDE (2012) and Gils (2014). 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. (2018).
In this study, we are especially interested in the quantitative assessment of technical as well as other structural and motivational factors influencing the DR potentials of the service sector. 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. To motivate companies to participate in DR measures, we already know that financial aspects alone will not be sufficient. Yet, obstacles and restraints have not yet been clearly identified. We would therefore like 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 (2018) 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 what the technical and attitudinal conditions currently are. After that, the estimation of potentials and the analyses of drivers, barriers and influencing factors are described. The paper closes with recommendations and conclusions on how the service sector's potentials can best be utilized.

2 Data and Methods

In summary, we provide a comprehensible and detailed estimation of DR potentials of the service sector on the level of its available flexible appliances. We therefore use empirical survey data on the availability of appliances and benchmarks taken from the literature to estimate the average consumption and shiftable demand in each sector and company size. Additionally, we take the willingness of the companies to participate into account, determining the practical potential. We also take a look at the most important barriers to and drivers of DR measures and how these influence the willingness for DR. This allows us to identify the most promising target groups and to give recommendations on how to tap into the potentials.

We conducted a standardised survey of the most relevant service sub-sectors in Germany (offices, trade and hotels/restaurants). Table V-2 shows structural data regarding the number of enterprises and the electricity consumption of the subsectors. Table V-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 V-2: Structural data for the service sector – electricity consumption and number of enterprises in Germany

Sector	**Subsector**	**Electricity consump. TWh/a, 2013**	**Share of consump. of selected sectors**	**No. of enterprises [1000]**	**Share of companies in sel. 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 Restau-rants	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. (2015) and DeStatis (2015)

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., 2018) 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. 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 (DeStatis, 2015). We assumed that medium and large enterprises would be the companies most interested in and most suited for conducting DR. We categorized the companies 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 (DeStatis, 2015). The weighting procedure we therefore applied was developed by the GfK Germany based on the linear weighting approach of Cassel et al. (1976) to optimize the distribution for number of employees and subsector.

We cleaned the data on the parameters of available appliances for erroneous values using the outlier labelling method (Hoaglin and Iglewicz, 1987). This procedure is able to detect highly unlikely values in normally distributed data. As is typical for energy related parameters (Schlomann et al., 2015) 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 V-3 shows the structure of our final sample containing 1584 complete datasets:

Table V-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**
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**

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 DR potentials

As the first part of the study we rate the potentials for each subgroup, using data on the availability of flexible appliances to estimate their electricity consumption. Following Wohlfarth et al. (2018) 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 (Table V-11, 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 (2007). Table V-12 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. In addition, sensitivity analysis reflects uncertainty in assumptions and reports magnitude of changes (cp. Table V-13).In addition to the technical potential, we estimate the practical potential referring to the share of companies willing to conduct such measures (cp. Table V-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., 2018). 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 (Reiter et al., 2018) 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 in high resolution.

Theoretical potential

The theoretical potential corresponds to the total demand of all flexible appliances. 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 average consumption parameters shown in Table V-11. 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 potential that can be used flexibly without omitting the actual function of the appliance, based on assumptions about frequency, duration and ratio of shiftable consumption and maximum load, taken from Klobasa (2007). The flexible shares are calculated for each of the flexible appliances (cp. Table V-12), 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 about technical restrictions, 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 V 13, for adjustment of assumptions cp. Table V-12).

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

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 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 "willing share" is thus used on each subsector and size cluster.

$$P_{pract} = \sum_1^s P_{tech,s} * w_s \qquad \text{(Equation 3)}$$

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 V-11)
a_i = availability of appliance i [0; 1]
l_i = specific load management share of appliance i (cp. Table V-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. (2015), applying the assumptions of flexibility shares from Klobasa (2007) and the assumption of Stadler (2005) 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 (2007) 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 (Wolf et al., 2016). Since heat pumps are not included in the study by Klobasa (2007), their consumption for the sector is taken from Kleeberger et al. (2016) and again adjusted to the share of our selected subsectors (60%) using the assumption from Wolf et al. (2016). The flexible share of heat pumps is estimated by transferring the parameters from Agora (2013) to the respective data of our subsectors.

2.2 Factors influencing the willingness to conduct DR

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 (c.p. the expectancy-value theory (Atkinson, 1957) and expectancy theory (Vroom, 1964), theory of planned behaviour (Ajzen, 1991). 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 V-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.

Our outcome 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 management is involved in decisions on DR.

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. (2004, 2011) and Cagno et al. (2013). 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. The final set of barriers and drivers is shown in Figure V-1.

3 Results

3.1 Conditions and status quo of DR 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.

3.1.1 Status quo of DR, 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 V-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 V-4: Experiences in DR

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 V-14, appendix): Restaurants and hotels with restaurants conduct DR most often with 18 and 11%, respectively. In hotels without restaurants, DR seems uncommon. 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 DR 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 DR. Our evaluation of the potentials for possible target groups (companies from different subsectors and of different sizes) integrates different aspects: the technical potential given by 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 conduct DR is of particular interest, because it distinguishes the technically available potential from the realistically usable potential (practical potential). The column "willingness" in Table V-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.

Table V-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 V-5: Evaluation of target groups for DR

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 V-6 summarises the weighted estimated theoretical, technical and practical 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, for example, 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 V-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 V-7).

Table V-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 (2007) 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

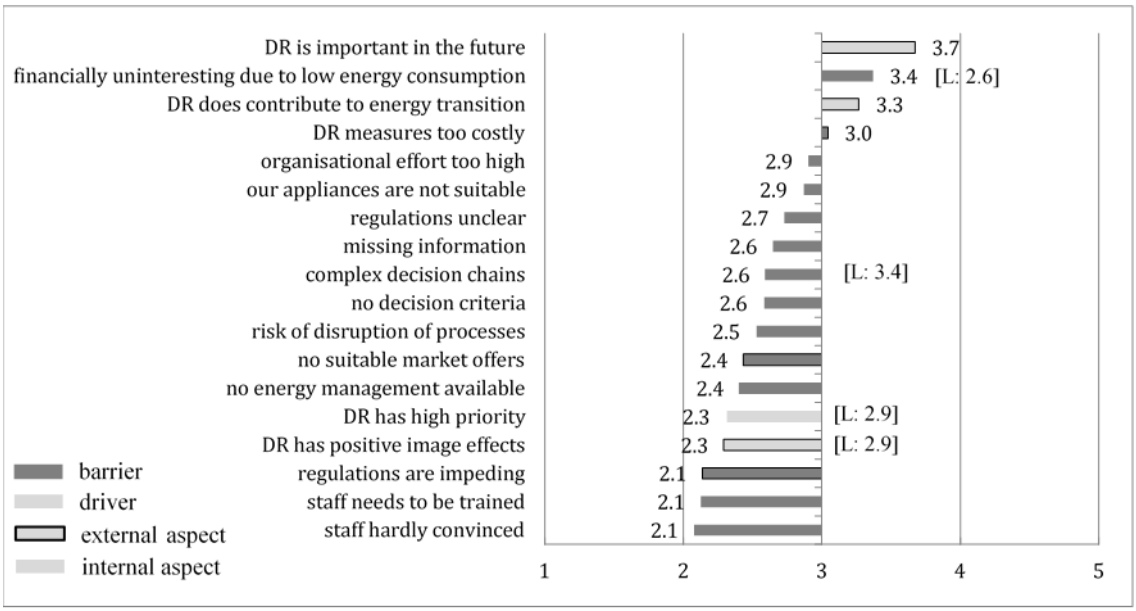
Besides the general statements on the willingness to use DR and the availability of technologies and appliances, we also asked questions about the acceptance of DR for specific appliances. We evaluated the appliances that are already integrated in DR and those that are potentially suitable for automated DR from the viewpoint of the companies. Thus, the following results always 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 (BMWi, 2017). 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 DR

For the barriers and drivers towards DR the participating companies were asked to rank statements about DR on a 5-point Likert-scale (1: low agreement, 5: high agreement). Figure V-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.

Figure V-1: Rating of barriers with respect to DR (weighted mean)



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 V-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 DR and the priority of DR

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"), it is necessary to relate them to a practical feasibility rating (i.e. the willingness to conduct DR) and how DR becomes a priority of the management department of companies in order to discover more about the conditions needed to facilitate DR action.

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 V-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 V-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 V-8: Influencing factors on the willingness to conduct DR measures

Outcome variable	**Predictor variables with significant influence (β)**		**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 outcome 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 V-5 and Figure V-1), it is to be assumed that the influencing factors differ within subgroups of company sizes. Table V-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 V-9: Regression on willingness to conduct DR - differences between company sizes

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

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 considered their options for DR, it is also interesting 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 V-10 shows the influencing variables on the prioritisation of DR. The perception of positive image effects on customers has the strongest influence, which means that greater visibility of DR for the customer could raise the interest of companies of the service sector. Enterprises that already have experience and knowledge about energy consumption (i.e. have already conducted an energy audit) 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 cannot 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 V-10: Factors influencing the priority of DR measures

Outcome variable	**Predictor variables with significant influence (β)**		**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.

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 (Wohlfarth et al., 2018). Companies best prepared, technically equipped and willing to conduct DR are enterprises in the subsector food retail as well as restaurants. 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 earlier results.

An earlier modelling approach by VDE (2012) 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 service sector while having a particular high proportion of the considered flexible appliances (compared to other service subsectors, cp. Wohlfarth et al., 2018), our results of approximately 3.8 TWh of technical potential seem comparably low. This could be due to our conservative assumptions based on Klobasa (2007) of only 1-2 hours of load shift per appliance and day for most of the appliances considered. Nevertheless, these cautious assumptions were made in order not to risk conflicts with comfort or work processes through flexibilisation or to overestimate the potentials. As can be seen in the provided sensitivity analysis (cp. Table V-13, 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 cautious 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.

We also considered influencing "soft factors" in order to provide recommendations for targeting suitable enterprises and for being able to incentivise DR activities. 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. Compared to findings on barriers in industry, the positive image of DR on customers has a greater relevance for enterprises in the service sector. While profitability of measures always plays an important role, profitability seems to be stronger linked to positive image effects on customers in the service sector, whereas, in industry, preventing product quality losses mostly ensures profitability. In industry, possible interruption of processes complicates the integration of energy-intensive core processes in DR measures (Olsthoorn et al., 2015). The risk of disruption of processes in the service sector 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. (2016), 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, concerning 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 to enable a successful rollout of DR measures in the service sector. Raising attention and incentivising early participation are considered crucial for the success of innovations (Rennings, 2000).

In terms of methodical aspects, our primary quantitative data was 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, European Commission, 2003). 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.

It should be noted 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 penetration of e.g. AC and heat pumps will increase in the future (Dena, 2010; Stawiarski, 2014). This supposedly results in higher theoretical potentials, even in the face of energy efficiency improvements (VDE, 2012), 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

- Target groups and first-movers:
  In a rollout scenario to increase the share of companies participating in DR, target groups acting as pioneers could be enterprises that are willing and equipped and thus already well qualified for DR. In accordance with our qualitative assessment, the results of this study show that especially large enterprises with restaurants and the food retail/wholesale subsector seem to be eligible for future automated DR. These companies also have the most experiences with current DR options, which might imply smaller reservations towards future DR-measures. In innovation theory, early adopters are considered crucial to motivate next movers. The most suitable appliances to start with seem to be those already integrated in building management systems, which at the same time have a high rate of acceptance for automated control, i.e. AC/ventilation and cooling/refrigeration.

- Influencing the willingness to participate:
  However, besides technical preconditions and the availability of suitable appliances, the willingness to participate in DR-measures and therefore the practical potential is influenced by the perception of corporate operatives. Organisational "soft factors" can influence the willingness for and prioritisation of DR-measures.

  - Image effects and visibility:
    We found that customer image acts as a driver for the prioritisation of DR on management level. We assume that the typical close relationship between companies and their customers in the service sector explains the relevance of image effects here. This indicates that 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. Introducing a certification label for enterprises that have carried out such measures could help generating marketing value. Similar to the energy efficiency standards for buildings, the European Commission introduced a "smart indicator" in its EPBD (Energy Performance of Buildings Directive, European Commission, 2016), 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. In order to lower thresholds for DR decisions, assessment of barriers and drivers show, that management should be involved in decisions about DR, while at the same time DR-measures should require low organizational effort. This could be achieved by implementing standardized solutions for widely used cross-sectoral appliances.

  - 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 to realise their potentials.

  - Clarity of regulation:
    Clarity of regulation, incentives and information about the options involved are essential to promote DR participation. Currently low prices for flexible demand inhibit participation and give the impression that there is no need for DR. One example of current regulations, that essentially counteract the participation in DR measures to balance the grid is the StromNEV (2005, §19, sec. 1 and 2). It states that consumers with high loads can profit from special types of grid use, avoiding unpredictable peaks within the company-consumption and using electricity outside the high-load periods. Thus, causing peak loads in the consumption pattern of the companies by participating in DR-measures that aim to balance the grid at

intercompany-level could result in losing the privilege of lower grid charges. Along with the increasing share of intermittent renewable energy-sources in the grid, the need for stable consumption is expected to shift towards consumption-patterns, which follow the fluctuations of energy production more closely. This will increase the value of flexible demand and as a consequence, regulations and market conditions will have to change to incentivise different load patterns.

- Transferability of method and results:
  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 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. While our results refer to the service sector, the investigated appliances are widespread and also used in industry or households where they could be utilised for DR as well. Since, as we have seen in this study, influences on the willingness to participate in DR vary between sectors, conditions in households and industry need to be assessed separately but our results provide starting points for possible influencing factors as well as a comparison for the expectable sizes of effects.

Further research is needed on the financial incentives required to engage enterprises in DR. Practical field studies might be necessary to learn how to integrate DR into working processes and how to dismantle perceived barriers.

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Appendix

Table V-11: Parameters used to calculate demand

Subsectors	**Appliance**	**Unit**	**Parameter**	**Source**
All	Cooling room	kWh/m² pa	500	Evans (2007) Evans et al. (2014)
All	Freezing room		750	
All	Fridges	kWh/m pa	2000	Heinboke (2013) Steinmaßl (2013)
All	Freezer		2000	
Offices	AC	kWh/m² pa	40	Abela et al. (2016) Menezes et al. (2012)
Retail			110	
Hotels			35	
Restaurants			50	
Offices	Ventilation	kWh/m² pa	15	Benke & Leutgöb (2008)
Retail			30	
Hotels			15	
Restaurants			30	

Table V-12: 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 (2005, 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 V-13: 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 V-12. Percentages in brackets refer to the respective share of the total theoretical potential.

Table V-14: 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%

Chapter VI

The flexibility deployment of the service sector - a demand response modelling approach coupled with evidence from a market research survey

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Abstract

The flexible use of energy is seen as a key option to facilitate the integration of volatile renewable energy sources (RES) into the electricity sector. In this study, we focus on flexibility in the service sector, in terms of flexible technologies, experiences and willingness to participate in demand response (DR) actions. We analyse the technically possible future deployment of flexibility, the practically possible deployment of flexibility and also take the reduction of RES surplus electricity into account. Our results are based on survey data from over 1.500 service sector companies (offices, trade, hospitality) and modelling results with a time resolved DR model (eLOAD). The data show that service sector companies have few experiences in DR so far, which is among others caused by the unfavourable regulatory conditions to participate in flexibility markets. The currently most common forms of DR are load shedding and flexible tariffs and optimised purchase of electricity. Participation in DR varies between subsectors and company sizes, but on average all subsectors are interested in extending (automated) DR measures in the future. Our projections result in a possible technical deployment of flexible electricity of 7.74 TWh of which about 510 GWh can be used to reduce renewable surplus electricity (in case of a 50% RES share). In case of a 80% RES share, this can reach 1.63 TWh. Integrating the willingness of companies to participate in DR, the practical possible deployment results in 131 GWh reduction of renewable surplus electricity. This can be interpreted as a first-mover potential for DR. Future increased need for flexible demand could raise the profit for the companies and their willingness in participating in DR. Further analyses on most promising target groups of companies would help to tap the potentials and to create market offers as well as policies to incentivise participation.

1 Introduction

Over the course of the energy transition, the increase in volatile renewable energy sources (RES) will result in new challenges for the energy system. Flexible demand is seen as one way to mitigate these challenges and to ensure the security of supply, for example, by reducing peak loads and therefore potentially avoiding otherwise necessary network expansions, and by integrating electricity from renewable energy sources (RES). At present in Germany, mainly industrial enterprises participate in flexibility markets and their high loads compensate the fluctuations in supply (Weißbach, 2015). Future developments will raise the value of flexible demand and may involve less energy-intensive sectors as well (such as services and households). Regarding the service sector, the loads available at each business site are smaller, but are more widespread regionally and energy consumption does not affect their core business activities. Their loads usually can be shifted immediately, but only over short periods. These characteristics might make the service sector's flexibility potential especially interesting for load balancing on a regional distribution grid level. Therefore, it seems worth taking a critical look at the potentials and options for smaller consumers to take part in flexibility markets, particularly since many studies already assume a deployment of these flexibility potentials (e.g. Klobasa, 2007; VDE, 2012; Dena, 2010).

Measures to change electricity usage patterns on the demand side are referred to as demand response measures (DR, e.g. IEA, 2016). They aim to improve the utilization of variable renewable energy sources and support system stability. Furthermore, because they reduce the need for conventional power plants for load compensation and the need for additional electricity infrastructure, electricity prices can be lowered.

Different definitions of DR potential need to be distinguished (Rudolph and Wagner, 1997; von Roon and Gobmaier, 2010). The *theoretical potential* can be seen as the upper limit of potential, e.g. summing up the loads or the consumption of all appliances that can be used for DR purposes. The *technical potential* also considers technical constraints, such as temperature-dependent availability, e.g. in the case of air conditioning (AC) or heat pumps. The *economic potential* takes economic viability into account, assuming that measures are only taken if they are profitable. Profitability depends on economic parameters such as energy prices, and financial parameters such as discount rates. The *practical potential* depends on perceived barriers and organizational restrictions, which influence the decision to take DR action. Both the economic and the practical potential may be influenced by policy settings that could increase the uptake of DR options.

The described potentials refer to different levels of demand flexibility on the consumer side (here: service sector companies). This flexibility is only needed for certain timeslots (e.g. to smooth the residual load) and thus cannot always actually be deployed. Hence, besides the potential, another important parameter is the actually *deployed flexibility.* This is the share of the potential flexibility, which is actually deployed, depending on the need for flexibility due to the availability of energy compared to demand at different points of time, i.e. it

represents the amount of flexible electricity that is available and actually needed. It is therefore significantly lower than the technically available flexibility, since the need for flexibility on a national scale is often limited to hours with high PV production in summer or night hours with high wind production in winter. Not all the flexible technologies are available during these hours: for instance, air-conditioning is not usually available in winter. If the need for flexibility is reflected in electricity prices, the deployed flexibility is related to the economic potential, but differs in terms of price levels, additional efforts, investment costs and profitability calculations.

Previous studies have already estimated the DR potential for the service sector (Klobasa, 2007; VDE, 2012; Dena, 2010). Depending on the database, method and projected year, the calculated theoretical, technical and economic potentials vary between 5 and 10 TWh/a flexible energy for the service sector in Germany.

The economic potential, in particular, also depends on the financial compensation for providing flexibility and low payments hinder the willingness to participate in DR. In Germany, different options exist to market demand-side flexibility. They derive from the need for reliable supplements on the supply side, and they integrate flexible options of electricity consumption, e.g. for balancing and frequency reserves. Flexible loads can be traded on the balancing or spot market. Additionally, loads can be used for congestion management under the Ordinance on Interruptible Load Agreements (Abschaltbare Lasten Verordnung, AbLaV, 2016). Other forms of demand-side management include time-variable tariffs, where electricity prices vary over time depending on the availability of electricity.

On Germany's balancing market and under the Ordinance on Interruptible Load Agreements, flexible loads need to prequalify to fulfil minimum standards. The regulatory environment to participate in DR is less favourable than in other countries (SEDC, 2015). Bid sizes and reaction times vary between 1 and 5 MW and from seconds to 15 minutes, respectively. To open the market to more customers, bid sizes and bidding cycles have recently been adapted (SEDC, 2015). In the latest revisions, pooling of loads is also permitted, e.g. by third party actors like aggregators, as is the participation of medium voltage grids thus facilitating participation for smaller customers and smaller loads. A standardized process (aggregator model) for contracting and financial compensation between the parties is currently in the works and has been thoroughly discussed by the German regulatory agency Bundesnetzagentur (BNetzA, 2016) and other relevant stakeholders.

Predominantly large, energy-intensive enterprises or third party players participate in the above mentioned markets. This year, about 60 providers prequalified; most of the participating enterprises were from the industrial sector or energy providers (Regelleistung.net, 2018a). The service sector has not participated so far (Weißbach, 2015). Before the revision of the AbLaV in 2016, it was only accessible for larger loads, which systematically excluded companies from the service sector. Indeed, only thirteen

enterprises at the most participated under the previous ordinance (Regelleistung.net, 2018b).

In general, demand-side flexibility in the service sector is much less common than in industrial sectors. One reason is that most consumer loads do not fulfil the prequalification standards (e.g. minimum bids, guaranteed availability of loads, required technology and other technical/ organisational issues, cp. (VDN, 2007). The energy consumption of the available flexible appliances in the service sector is usually smaller than the appliances typically used in industrial companies. Pooling might become a feasible option in the service sector, especially once standards are established for the aggregation. However, the possible rewards are relatively small compared to the effort needed to participate in the market. More common demand-side options for flexible loads are minimizing peak loads or atypical grid loads which result in lower grid fees for the customer. In Germany, consumers with special types of grid use can profit from lower grid fees (StromNEV§19, sec. 1 and 2) if either their consumption exceeds 10 GWh within 7000 utilization hours (intensive use) or their peak consumption lies outside defined high-load periods of the network operator (atypical grid use). In some cases, these advantages counteract participating in other flexibility options, because load reductions or peaks due to balancing might result in losing the (higher) privileges under the StromNEV.

Variable electricity tariffs are characterized by prices that vary depending on time, load, consumption or load management issues (Nabe et al., 2009). The most common variable tariffs are time-of-use (TOU), critical peak pricing (CPP) and real-time pricing (RTP) that differ in the timespan of scheduling. In Germany, the EnWG (Energiewirtschaftsgesetz - German Energy Industry Act) obliges energy providers to offer variable tariffs. Currently, however, most energy providers use the simplest form of TOU tariffs with two price periods, e.g. day and night rates. Often these tariffs are combined with specific technologies like night storage heating. A few suppliers or aggregators already offer a kind of RTP tariff, where electricity prices vary depending on exchange prices (NEXT Kraftwerke, 2017). With the growing significance of renewable energies, the number of offers might increase.

Given the current developments in the energy transition and the energy system, the conditions for trading flexible energies will change. Recent revisions of the participation requirements for the balancing markets and the development of the aggregator model indicate the increasing importance of flexible loads and participating parties. To tap into a larger share of the potentials offered in the service sector, the economic incentives must be improved, because participating in the market under current conditions is either impossible or economically unattractive for less energy-intensive companies.

The aim of this study is to assess the technical and practical flexibility deployment in order to estimate the possible contribution of the service sector to flexible demand options. The technical flexibility potential considers the total technically available flexible load of the service sector. The practical flexibility deployment refers to the share of companies willing to conduct DR. The technical and practical flexibility deployment differs from the technical

and practical potential in that the former refers to the actually deployed flexible energy according to the actual need for flexibility. In contrast, the technical or practical potential describes the available flexible energy whether it is needed or not. We also estimate the economic benefit of the deployed flexibility on the basis of a real-time price. In the case of a real-time price, no prequalification standards need to be considered to evaluate the potentials unlike for the balancing market, for example.

We (i) examine the current state of DR actions and starting points in the service sector in Germany in a market research survey. The results include the assessed willingness of the service sector to participate in DR and an estimation of the accessible consumption provided by the flexible appliances in this sector. Using the insights gained, we (ii) calculate the technically and practically deployable share of flexible energy of the service sector using the time-resolved eLOAD[1]model (Boßmann, 2015), which optimizes the national DR deployment based on the least-cost scheduling of flexible loads. We conclude (iii) with an estimation of the economic benefits and an outlook to future changes in energy demand considering flexible appliances in the service sector.

2 Methods and Data

2.1 Market research survey

To evaluate the current state of flexible loads and the deployment of demand-side management in the service sector, a market research study was initiated within "EnSYS-FlexA" and "AVerS", two projects funded by the German Federal Ministry for Economic Affairs and Energy. The focus lies on estimating flexibility potentials while considering certain preconditions as well as restrictions and acceptance issues influencing the potential to use flexible loads for DR.

To focus on the most relevant subsectors of the service sector, we conducted a preceding deeper analysis of the subsectors' shares in electricity consumption and the availability of flexible cross-cutting technologies (cp. Wohlfarth et al., 2018). Cross-cutting technologies refer to technologies that are used across the whole service sector such as ventilation/air conditioning (V&AC), refrigeration/freezing (RF), heat pumps (HP), (electric) hot water heaters (HW) and night storage heaters (NSH). The results of this analysis indicated that offices, trade and hotels/ restaurants are the most relevant subsectors: Together they account for 70.5 TWh/a (i.e. more than 50% of the service sector's total electricity consumption and about 14% of Germany's total electricity consumption) with large shares of consumption in flexible cross-cutting technologies. The quantitative data we used as

1 www.forecast-model.eu

input for our approach are derived from a survey of our three selected subsectors. The data were collected between May and July 2017 with the help of a market research institute. The data were obtained using CATI (computer assisted telephone interviews) with the person in charge of energy issues at each company. The survey contained items on the measures taken regarding DR, plans to implement DR measures and general preparedness for automated DR options as well as facilitating conditions like BMS (building management system) or energy management systems. Our final sample contains 1584 complete datasets and is structured as Table VI-1 shows:

Table VI-1: Sample structure of the quantitative survey (derived from Wohlfarth et al., to be published)

Sectors	**Number of enterprises**	**Company size**	**Number of enterprises**
Offices	675	**Small**	456
Retail / trade	553	**Medium**	691
Hotel, lodging, restaurants	356	**Large**	437
Total		**1584**	

Large enterprises: more than 50 employees; medium enterprises: 10-49 employees; small enterprises: less than 10 employees

In order to assess a sufficiently high and comparable number of enterprises within every category of size and subsector, the distribution of enterprises is not representative regarding these characteristics. Thus, we weighted our results regarding sectors and categories of sizes according to the distribution in Germany given by the Federal Statistical Office (DeStatis, 2015) to obtain results in line with the representative population.

The survey also contained questions about the availability and dimensions of flexible appliances. On this basis, we calculated the energy consumption of flexible appliances for the surveyed subsectors (for details, see Wohlfarth et al., tbp). This consumption data is the basis for calculating the deployed flexibility using eLOAD.

Assessing the willingness of companies to participate in DR aims at analysing the practical potential, i.e. the share that will realistically contribute to the total deployed flexibility. In contrast to technical potential estimations, unwilling companies are not counted because their technical potential cannot be used. The willing share symbolizes “first-movers”, who are relatively easy to persuade and whose potentials are more easily accessible. On the other hand, although there is no guarantee that unwilling companies will ever participate, the willing ones can act as role models that may influence hesitant companies and make them more willing to participate.

2.2 The eLOAD model

We calculate the deployment of flexibility using eLOAD – a model that optimizes the scheduling of flexible loads to consume electricity in hours with low retail prices, therefore generating savings in electricity procurement through arbitrage. The eLOAD (energy LOad curve ADjustment) model (Boßmann, 2015) uses the share of flexible loads in the service sector and their total electricity consumption as input to calculate the optimal deployment of flexibility.

eLOAD addresses the active adjustment of the load curve through DR. In this study, we use eLOAD to determine the least-cost scheduling of flexible loads on the demand-side depending on an hourly pricing signal (real-time price). The hourly pricing signal is an exogenous model parameter and in our study, it is calculated based on the residual load[2] taken from Fraunhofer ISI et al. (2017), and adjusted after the deployment of each cohort of flexible loads. Since the pricing signal correlates with the residual load, the least-cost scheduling of the flexible load also simulates the potential contribution of demand-side technologies to residual load smoothing and RES integration.

Residual load smoothing enables the efficient operation of existing electricity generation assets and grid infrastructure as well as reducing the need for investment in new capacities (Boßmann et al., 2015). As mentioned above, a major input to the eLOAD are the hourly generation profiles of renewable energy sources. Most of the renewable energy sources are characterised by volatile supply. In 2017, Germany already reached a RES share of 36% in gross electricity consumption (AGEB, 2018). The target share of renewable energies in gross electricity consumption in 2030 is 50% as stated in the German government's "Energiekonzept" (Deutsche Bundesregierung, 2010). The coalition agreement of 2018 intends to increase this target to 65% (Bundesregierung, 2018). When modelling our results, we assumed a share of about 50% of renewable energy sources in the power mix. We also analysed an additional scenario with an 80% share of renewable energies for sensitivity purposes.

The specific shares assumed for renewable energies in net electricity generation are: 15% PV (47.2 TWh), 41% onshore wind (112.0 TWh), 25% offshore wind (69.1 TWh) and 17% others (e.g. biomass) (45.1 TWh). The total final electricity demand in Germany is 520 TWh in this scenario. Time resolved renewable electricity production and production profiles are taken from the base scenario of the long-term scenarios of the German Ministry for Economic Affairs and Energy (Fraunhofer ISI et al., 2017, p.223, Table 60). We refer to this scenario as the 50%RES-scenario.

The optimal load schedule for processes that are particularly suited to DR is calculated with eLOAD based on the electricity consumption pattern (i.e. the load profile) of the respective process, as well as techno-economic parameters and restrictions (e.g. capacity, storage or

2 The residual load equals the system load minus the generation of fluctuating renewable energies.

organisational constraints). A mixed-integer optimisation is carried out to determine the least-cost scheduling of the load under the assumed price signals. The objective is formally described as

$$Min \sum_{i=h_{min}}^{h_{max}} \sum_{j=i+ct+h_{max}-1}^{i-ct+h_{max}+1} \{ls_{ij} \cdot [p_j \cdot (1 + |j - i| \cdot cif_{ls}) - p_i]\}$$

where $i \neq j$ and $i, j \in [h_{min}; h_{max}]$ i.e. $i, j \in [0, oi - 1]$. With the shifted load ls, the optimisation interval length *oi,* the cycle time *ct*, the consumption increase factor *cif,* the hourly electricity price *p* [16].

As a result, the model delivers a quantitative assessment of deployed load shifting, providing detailed information about the seasonal, weekly and hourly load shifting availability of the individual appliances. It generates a smoothed residual load curve that can be used in an electricity market model to quantify the impacts of DR on the electricity system.

eLOAD is an established model that has frequently been used in German and European studies for policy makers and industrial customers (Fraunhofer ISI et al., 2018). For this study, the methodology to represent the share of flexible technologies in the model was complemented by the consumers' willingness to provide flexibility for the energy system; this reflects the practical potential. Using empirically assessed data on electricity consumption and adding the aspect of willingness derived from the survey data is a methodological improvement compared to the former approach. We also estimate the deployed flexibility of the service sector: The technically deployed flexibility assumes all companies participate in DR with their flexible appliances. We refer to the practically deployed flexibility (or first-mover flexibility) if only willing companies participate.

2.3 Assessing the flexibility potential of the service sector

The total consumption of all the flexible appliances together can be regarded as the theoretical potential provided by service sector companies. The actually deployed flexibility is smaller, because the total theoretical potential can neither be used technically nor is it always required when available. The actual deployment involves the load profiles or the need for flexible electricity to smooth the load profiles and assumptions regarding technical restrictions on using the flexible appliances for DR. In order to calculate the actual flexibility deployment, we include this consumption data (theoretical potential) in the eLOAD model.

In the following sections, we compare the deployed flexibility if 100% of the service sector's flexible consumption is available (technical deployment) vs. if only willing companies participate in DR (practical deployment).

Thus, we distinguish the following concepts:

- *Consumption of flexible appliances:* The electricity consumption related to flexible technologies, i.e. V&AC, RF, HP, HW and NSH. This can be seen as a theoretical potential and is the basis for modelling the technically and practically deployed flexibility.
- *Technical flexibility deployment:* This is the electricity consumption of flexible technologies of the service sector deployed to smooth the residual load. Compared to the consumption of flexible appliances, appliance-specific parameters for load shifting (e.g. maximum duration of load shift and availability of appliances depending on time and season) are taken into account as well as the need for flexibility depending on the residual load. It is assumed that 100% of the companies of our selected subsectors of the service sector participate in DR.
- *Practical flexibility deployment:* This uses the same determinants as the technical flexibility potential but additionally takes into account the willingness of companies to participate in DR (as determined from the survey), i.e. not 100% of the sector's companies participate in DR. Only the willing companies contribute to the total flexibility deployment.
- *Reduction of RES surplus*[3] *electricity:* We use this exemplary concept to show that more flexibility is not necessarily better in every case: The generation of renewable electricity varies during the year and depending on weather conditions, so renewable surplus electricity and the availability of flexible technical appliances do not always match in time and amount. Therefroe, the RES surplus that can be reduced using flexible appliances is only a share of the total technical flexibility deployment.

3 RES surplus: when the residual load reaches negative values it can be taken as an indicator that (locally) the renewable electricity production exceeds the electricity consumption.

3 Results

3.1 Flexible shares and willingness to provide flexibility - results of the market research survey

3.1.1 Current state and future options of demand response in the service sector

Based on our weighted survey data, we calculated the shares of enterprises in Germany in our selected subsectors that already conduct DR (temporal adjustments in electricity consumption, including time shifting or load shedding) and those who are generally willing to do so (Table VI-2). Our definition of DR willingness is described below.

Table VI-2: Current and future DR in the service sector (% refer to the share of companies)

Sectors	**Share of enterprises conducting DR**	**DR willingness ***	**Company Size**	**Share of enterprises conducting DR**	**DR willingness**
Offices	1.6%	12.8%	**Small**	3.1%	13.7%
Trade	4.2%	17.3%	**Medium**	6.3%	19.4%
Hotel, lodging, Restaurants	10.7%	31.8%	**Large**	14.6%	29.2%
Total	3.5%	16.5%	**Total**	3.5%	16.5%

* DR willingness includes the companies already conducting some kind of DR and those stating they can well imagine conducting automatically or externally controlled DR.

The share of companies who already conduct DR differs regarding size and subsector. The highest shares are enterprises trading and dealing with food (food retail and restaurants). The size of enterprises also plays a role, with large enterprises (more than 50 employees) conducting DR significantly more often than small ones. However, the service sector features the largest share of enterprises with fewer than 10 employees, so they should not be left out of our calculations.

Only a small share (3.5%) of the total sample already conducts DR. Different DR options were possible as were multiple options: Most of the enterprises already conducting DR do load shedding (about 57%, lowering the peak load). Time-variable tariffs, optimized purchase of electricity (e.g. at the power exchange) and bilateral agreements (i.e. individual contract, e.g. concerning power cut-offs) are also common with between 20 and 30% of enterprises. Time-variable tariffs are stated more often in offices; optimized purchase is more common in the trade sector than in the other sectors, while bilateral agreements were rarely mentioned in the trade sector.

To learn more about the potentials for DR in the service sector, we also asked if the participants of the survey could imagine implementing DR in their company, i.e. automatically or externally controlled reactions to price signals. The answers were given on a 5-point Likert-scale between "definitely not" (1) and "definitely yes" (5). Those companies that stated they would at least agree to participate (rating 3 to 5) or those that already conduct DR (i.e. optimized energy purchasing, time-variable tariffs, load shedding, participation in balancing markets, or agreements on load cut-offs) were counted as "willing to conduct DR". According to their answers, the willing share in the selected subsectors of the service sector is 16.5%; again, the shares vary between the subsectors.

3.1.2 Flexible electricity consumption in the service sector

Besides the willingness to use it, the specific DR potential depends especially on the availability of flexible appliances and their electricity consumption.
Table VI-3 shows the yearly consumption of flexible appliances in the service sector. The numbers for V&AC and Refrigeration are taken from Wohlfarth et al. (tbp); the numbers for hot water, HP and NSH are derived from Schlomann et al. (2015) (water), Kleeberger et al. (2016) and Wolf et al. (2016) (heat pumps), and Klobasa (2007) and Wolf et al. (2016) (night storage).

Table VI-3: Consumption of flexible appliances in the three selected subsectors of the service sector in 2017 in GWh/a (derived from Wohlfarth et al., tbp)

Electricity consumption in GWh/a		**Offices**	**Trade**	**H&R**	**Total**
V&AC	ventilation	650	1195	429	2273
	AC	1552	3704	304	5560
Refrigeration and freezing (RF)	fridges	53	1252	1768	3073
	freezer	11	581	934	1527
	cooling room	18	2863	849	3730
	freezing room	9	608	324	942
Hot water (HW)	electric water heating	900	700	1300	2900
	Sum	**3193**	**10904**	**5907**	**20004**
HP	heat pumps				298
NSH	night storage heating				1785
	Total				**22087**

H&R: Hotels, lodging & Restaurants, Trade: Wholesale & Retail trade

Table VI-3 shows that especially air conditioning and cooling rooms have a high share in the total electricity consumption of the service sector companies, but they are not equally distributed over the different subsectors. Trade accounts for more than half of the total consumption of the analysed subsectors.

3.2 Technical and practical flexibility deployment - results of the eLOAD model

Table VI-4 lists the electricity consumption of the processes in the service sector that are considered for modelling flexibility deployment under the condition of increased renewable integration (section 2.2) and gives the options for load shifting: The scheduling of circulation pumps and V&AC is limited and can be shifted by 1 hour maximum to ensure a constant provision of heat and fresh air and thus comfortable conditions. Additionally, we assume that AC is only used at high temperatures. Heat pumps, hot water and refrigeration processes are considered to be equipped with a physical storage, e.g. a hot water tank. Their load shifting potential is calculated endogenously in the eLOAD model, considering storage restrictions and the hourly storage discharge; for details, see Boßmann (2015).

Table VI-4: Shifting parameters of flexible appliances

Appliance		**Electricity consumption GWh/a**	**Avg. hourly usable storage capacity in MWh[4]**	**max. load shifting duration[5]**
V&AC	ventilation	2273	-	1h
	AC	5560	-	1h
Refrigeration and freezing (RF)	fridges	3073	+/- 945	1h
	freezers	1527	+/- 480	1h
	cooling rooms	3730	+/- 867	24h
	freezing rooms	942	+/- 243	24h
Hot water (HW)	electric water heating	2900	+/- 795	24h
HP	heat pumps	298	+/- 231	24h
NSH	night storage heating	1785	+/- 5,660	24h

V&AC: Ventilation & Air-conditioning, RF.: Refrigeration and freezing, HW: Hot water, HP: Heat pumps, NSH: Night Storage Heaters

When modelling the technical flexibility deployment, we use these shifting parameters and the specific consumption (Table VI-4 and section 3.1.2) of each flexible appliance, assuming that all appliances present in the companies are generally available for flexible use. The

4 Amount of shiftable load and frequency depend on the available storage capacity. The storage size is calculated endogenously in the model; for details, see Boßmann (2015).

5 The maximum load shift duration is an exogenous model parameter. The load shifting duration of appliances without a storage is limited to 1h to avoid loss of comfort. Appliances with a storage can shift their loads in an interval of 24h, since electricity prices are currently available one day ahead in Germany.

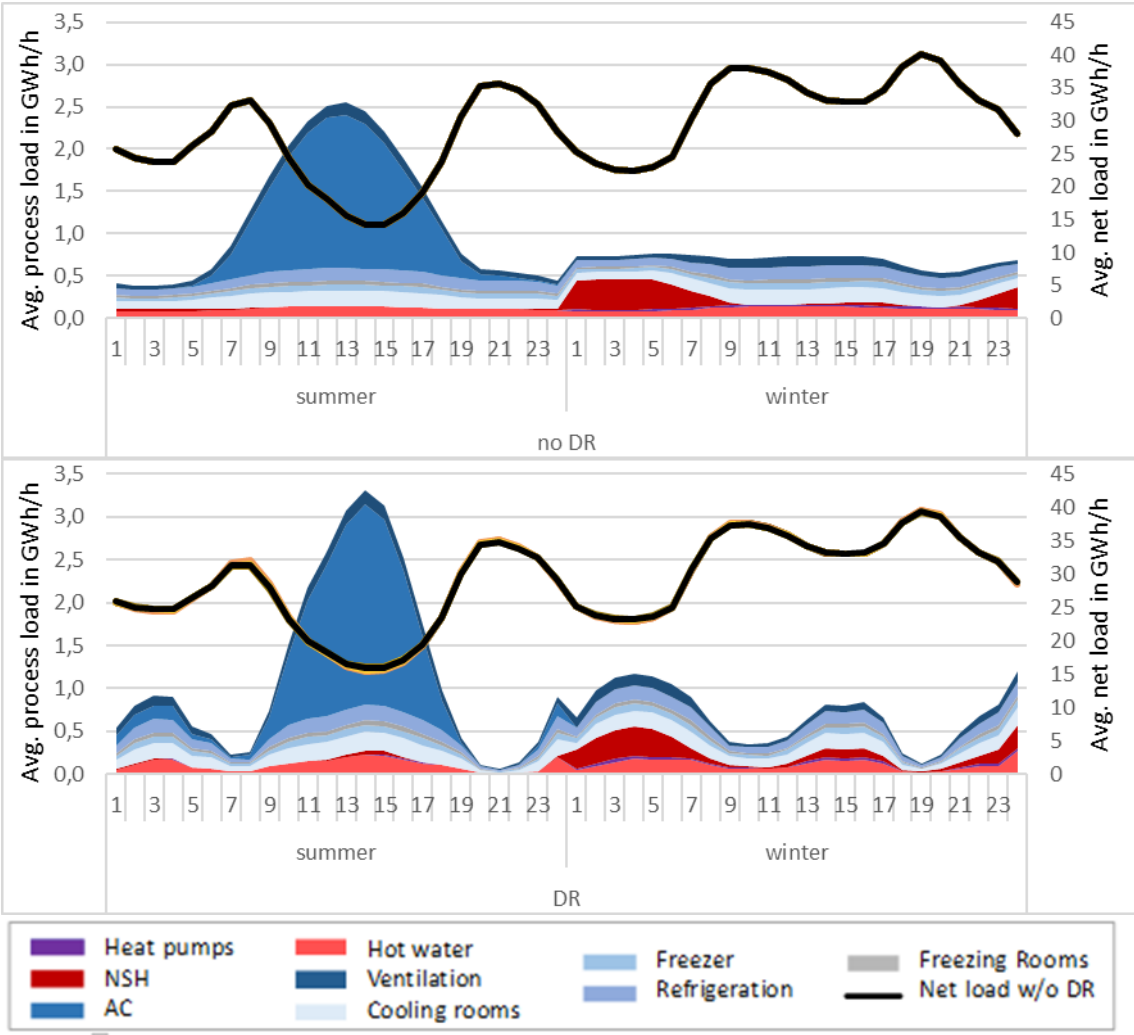
practically deployed flexibility involves only the share of companies that stated their willingness to participate in DR.

In the following, we analyse the described scenario with 100% availability of the flexible technologies (section 3.2.1) and compare it to the practical case including data from the survey on the willingness to participate in DR (section 3.2.2). The economics of the flexibility deployment are assessed in section 3.2.3 in the case that electricity price arbitrage (difference between peak and off-peak prices) is the source of economic benefit.

3.2.1 Technical flexibility deployment - results of the 100% participation scenario

We first look at the average uncontrolled load profiles of the considered processes in the service sector (Figure VI-1 upper graph, for details on the load profiles, see (Jakob et al., 2014). The consumption for heat provision is increases in winter and the heating profiles are characterized by more or less continuous electricity consumption over the course of the day, and a large share of consumption at night in the case of night storage heating (NSH). The consumption for ventilation and air-conditioning is higher in summer, which is due to the demand for air-conditioning that only occurs on hot days. The electricity consumption for ventilation and air-conditioning as well as for refrigeration already coincides quite well with the low residual load during summer midday hours (due to high shares of renewables in the scenario). In winter, the residual load has the lowest values in the early morning hours that feature no particularly high electricity consumption.

Figure VI-1: Average process loads (area plot, left scale) and residual load (black line, right scale) in the 50%RES-scenario, uncontrolled (above) and with 100% participation of DR options (technical deployed flexibility) (below).



When considering DR (Figure VI-1 bottom figure), the load is shifted primarily towards midday hours and early morning hours with a relatively low residual load in summer and winter (i.e. where renewables are abundant). In summer, the shift towards midday is more favourable, while early morning hours are preferred in winter. Overall, the largest flexibility can be provided by ventilation and air-conditioning processes, but, most of this can only be provided in summer. For both seasons, refrigeration and freezing processes show the highest available flexibility since the refrigeration chambers have a large internal storage.

Our analysis of flexible processes across the different subsectors reveals that V&AC has the highest electricity consumption and also results in the highest flexibility potential (Table VI-5). The same goes for the subsector trade that shows by far the highest electricity consumption in the considered processes (51% of the total subsector electricity demand) and thus the highest load shifting potential.

Table VI-5: Technical flexibility deployment in TWh/a (50%RES-scenario) in the selected subsectors

	Unit	V&AC	RF	HW	HP	NSH	Total
Total	TWh	2.75	2.64	1.22	0.13	0.99	7.74
H&R	TWh	0.26	1.28	0.67	0.04	0.33	2.59
Offices	TWh	0.94	0.02	0.31	0.06	0.44	1.77
Trade	TWh	1.55	1.33	0.25	0.03	0.22	3.38

V&AC: Ventilation & Air-conditioning, RF.: Refrigeration and freezing, HW: Hot water, HP: Heat pumps, NSH: Night Storage Heaters

Table VI-6 lists the flexibility deployed to smooth the residual load and the contribution of each process to integrating RES electricity in the residual load in the case of the technical flexibility deployment (all companies participate in DR). In our calculations, V&AC processes already provide about 36% of the flexibility in the service sector, followed by refrigeration and freezing with about 34%. Regarding the contribution of the appliances to reduce surplus energy, the relations slightly differ: V&AC provide over 35%, followed by refrigeration and freezing with about 28%. Most of the RES surplus electricity occurs in sunny summer midday hours when V&AC show particularly high availability.

Table VI-6: Summary of flexibility deployment for different processes (50%RES-scenario) in the selected subsectors

	Unit	V&AC	RF	HW	HP	NSH	Total
Electricity consumption of flexible technologies	TWh	7.83	9.27	2.90	0.30	1.79	22.09
Technical flexibility deployment	TWh	2.75	2.64	1.22	0.13	0.99	7.74
Reduction of RES surplus electricity	GWh	181	143	12.8	68.8	104.5	510

V&AC: Ventilation & Air-conditioning, Refr.: Refrigeration, HW: Hot water, HP: Heat pumps, NSH: Night Storage Heaters

Table VI-7 shows the deployment of flexible service sector technologies over the year. AC is only relevant in the summer and can therefore only be used then to make the electricity system more flexible. Conversely, heaters are hardly used in summer. Cooling appliances that are operated all year round can also be used in winter. In general, higher capacity utilization is achieved in winter.

Table VI-7: Normalized shifted load for the different processes. The values are normalized to the month with the highest shifted load (eq. 100%) load in the 50% RES-scenario.

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
AC	0%	0%	0%	2%	4%	46%	100%	42%	5%	0%	0%	0%
Cooling room	100%	86%	91%	84%	85%	83%	84%	88%	87%	93%	94%	95%
Freezer	100%	87%	91%	82%	86%	81%	83%	87%	88%	93%	94%	96%
Freezing room	100%	87%	92%	84%	86%	83%	85%	87%	88%	94%	94%	96%
Hot water	100%	90%	95%	85%	87%	89%	88%	88%	90%	94%	94%	94%
HP	84%	86%	100%	87%	59%	25%	8%	15%	49%	87%	84%	85%
NSH	74%	74%	100%	72%	49%	11%	0%	6%	37%	74%	72%	80%
Fridges	100%	87%	92%	85%	87%	83%	85%	88%	89%	93%	94%	97%
Ventilation	100%	87%	84%	75%	79%	65%	65%	70%	76%	82%	95%	98%

Table VI-8 shows the contribution of the service sector to reducing surplus RES in GWh. The final line shows the RES surplus before DR (in yellow). The results show that, in sum, about 20% (510 GWh) of the total RES surplus (2.5 TWh) can be absorbed by the analysed service sector subsectors (offices, trade, hospitality). In specific months with low RES surplus, almost all the surplus electricity can be reduced with flexible appliances from these sectors.

Table VI-8: Contribution of the service sector to reducing the RES surplus in the 50% RES-scenario (GWh)

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	
AC	0.0	0.0	0.0	0.0	0.0	4.2	65.6	42.6	1.7	0.0	0.0	0.0	114
Cooling room	1.2	2.1	8.6	0.4	2.8	0.3	4.1	6.7	6.4	7.3	6.5	6.1	53
Freezer	0.7	1.2	3.4	0.0	1.6	0.1	1.7	2.9	2.8	3.3	3.3	2.8	24
Freezing room	0.3	0.6	2.3	0.0	0.9	0.1	1.2	1.7	1.7	2.0	2.0	1.8	15
Hot water	1.5	2.3	10.3	0.3	5.1	1.2	6.7	8.8	8.3	10.8	7.1	6.3	69
HP	0.2	0.6	2.3	0.0	1.5	0.2	0.3	0.6	1.4	2.9	1.5	1.3	13
NSH	2.2	6.0	22.3	1.3	12.1	0.8	0.0	2.2	7.2	27.7	11.2	11.6	105
Refr.	1.2	2.3	8.2	0.3	3.4	0.3	4.3	6.2	5.4	6.7	6.9	7.2	52
Ventil.	1.7	2.5	10.3	0.0	3.8	0.1	6.2	7.9	7.4	10.2	8.8	8.3	67
Total	9	18	68	2	31	7	90	80	42	71	47	45	510
% RES surplus reduction	64%	62%	23%	100 %	20%	81%	40%	18%	14%	19%	25%	21%	20%
RES surplus	14	282	298	2	157	9	224	454	292	367	187	219	2505

The contribution of the service sector's flexible demand to the integration of RES is relatively small, as the flexibility options in the service sector can be deployed frequently (i.e. every day), but can only shift their loads for a few hours and in an interval of only one day. Therefore, if RES surplus occurs (almost) throughout the day, its reduction is hardly possible, because consumption cannot be shifted from hours without surplus to hours when RES surplus occurs. In this case, the flexibility options of the service sector only have a smoothing effect on the load. The difference between the reduction of RES surplus (510 GWh) and the technical flexibility deployment (7.74 TWh) implies that the service sector has the potential to contribute even more to reducing the RES surplus, but the availability of flexible loads does not match the surplus of renewable energies. In the 50% scenario, RES surplus is relatively concentrated in some periods, especially in autumn.

We therefore additionally analysed a scenario with a higher share of renewable energies, because we assume that this would increase the overlap of available flexible loads and RES surplus. The scenario with an 80% share of renewable energies (which is comparable to the target share of 2050, Deutsche Bundesregierung, 2010) shows that the reduction of RES surplus by the service sector would then be more than three times as high as in the 50% scenario (Table VI-9). Although the shifted load is the same as in the 50% scenario, the reduction of surplus RES is much higher in the 80% scenario, since situations with RES overproduction occur more frequently in the 80% scenario and the available flexibility in the service sector reduces negative residual load situations rather than merely smoothing the load curve.

Table VI-9: Shifted load and RES surplus reduction in the 80% RES-scenario

	Unit	**Technical**
Flexibility deployment (shifted load)	*TWh*	7.75
Reduction of RES surplus electricity	*TWh*	1.63

3.2.2 Practical flexibility deployment - results of the "realistic" participation scenario

16.5% of service sector companies say they are willing to conduct automated DR measures in the future. It can be assumed that the share of willing companies will increase if the regulatory framework improves and there is incentivizing regulation. Especially the companies with high technical flexibility potentials (large companies and companies from the subsectors trade and restaurants) show significantly more interest in carrying out DR measures. This share can be seen as a first-mover potential. The above discussed technical flexibility deployment that assumes 100% participation of the regarded subsectors is reduced here, because only willing companies can be taken into account when estimating the practical potential. If only the willing share of companies contributes to the deployment of flexible energy, the practical flexibility deployment is reduced to 1.82 TWh (24% of the technically deployed flexibility).

This value is close to the weighted (i.e. representative) total sector willingness to deploy flexible technologies of 16.5% from the survey (see Table VI-10). The difference stems from the fact that the first MWh of flexibility is of the greatest value for the system. In cases where only a small amount of electricity needs to be shifted, it can be compensated with the practically deployed flexibility.

Table VI-10: Summary of technical vs. practical flexibility deployment in the service sector

	Unit	Technical	Practical	ratio practical/technical.
Consumption of flexible appliances	*TWh*	22.09	3.64	16.5%
Flexibility deployment (shifted load)	*TWh*	7.74	1.82	24%
Reduction of RES surplus electricity	*GWh*	510	131	26%

3.2.3 Economic benefit of the flexibility deployment

Financial profitability is an important incentive to participate in DR. We assume the electricity price depends on the residual load. To assess the economics of flexibility deployment, we therefore calculate the future electricity price using a polynomial function that connects the residual load of the eLOAFD model in 2030 with the electricity price (Dallinger, 2012). This approach is comparable to a real-time price for flexible demand. The price $C(t)$ in EUR/MWh with residual load $P(t)$ in GWh is calculated using the following equation:

$$C(t) = c_3 P(t)^3 + c_2 P(t)^2 + c_1 P(t) + c_0$$

with the hourly electricity price $C(t)$, the residual load $P(t)$, and the regression coefficients $c_3 = 0.0008$ $c_2 = -0.0922$, $c_1 = 5.0624$ and $c_0 = 27.415$. For a residual load equal to zero or negative, a linear correlation is used:

$$C(t) = P(t) + c_0$$

The described function was developed by Dallinger (2012) based on experiences with the clearing results of an electricity market simulation model. The resulting hourly price time series shows an average price of $\bar{C} = 109$ EUR/MWh (considerably higher than the average in 2017: 32.9 EUR/MWh[6]) and an average spread of $\Delta C = 6$ EUR/MWh between two consecutive hours. The price depends on the residual load and changes when the load curve changes.

6 Source: EPEX; taken from Fraunhofer ISE (https://www.energy-charts.de/price_avg_de.htm?year=all&price=nominal&period=annual)

Applying this price function, we find that 23 EUR/MWh per year can be achieved on average for each shifted MWh of electricity. The analysed sectors stand to gain around 178 million euros in revenue from the technical flexibility potential of 7.74 TWh.

3.2.4 Future development of energy consumption

We base our calculation of the consumption of flexible appliances on empirical data from 2017. It can be assumed that consumption might change in the future and thus also the available share of flexible demand. We therefore refer to data from Fraunhofer ISI et al. (2017) considering developments until 2030. Due to efficiency measures, the service sector sees decreasing electricity consumption between 2017 and 2030. The decrease is particularly due to improved energy efficiency and the phase-out of electric storage heating. Storage and direct electric heating are replaced with heat pumps by 2030. Table VI-11 shows the changes in consumption for each flexible technology.

Table VI-11: Electricity consumption in 2030 of potentially flexible processes in the service sector and its development between 2017 and 2030

	Unit	V&AC	RF	HW	HP	NSH	Total
2017	TWh	7.83	9.27	2.90	0.30	1.79	22.09
2030	TWh	7.83	7.69	1.33	0.35	0	18.20
2017 vs. 2030		0%	-17%	-54%	17%	-100%	-18%

Source: Fraunhofer ISI et al. (2017)

The consumption of V&AC stays more or less the same. Although there will be gains in energy efficiency, the number of AC systems is expected to increase in the future. The number of NSH will decrease to the benefit of heat pumps, so the ratios change between the appliances contributing to the deployed flexibility. The overall consumption and the flexible potential will decrease, but incentives (affecting the willingness to participate, e.g. regulations and the increasing value of flexible demand) as well as improved technological standards facilitating the controllability of appliances will increase the realistic flexibility potential.

4 Summary and Discussion

Our results show that only a small share of the considered subsectors from the service sector conduct DR so far (about 3.5%). The most common DR measures are load shedding, flexible tariffs and optimised purchase of electricity. One reason for the low share of companies from the service sector are the unfavourable regulatory conditions that impede participation (e.g. prequalification criteria, difficult market access/ difficulties with load aggregation). In other countries with more favourable regulatory conditions, the

participation in DR is higher (SEDC, 2017, Reiter et al., 2018). Due to the fact that service sector companies use fewer energy-intensive cross-cutting appliances and due to the large share of small companies in this sector, DR is also financially less attractive. Automatic or externally controlled DR measures are considered to tap the maximum potential. In our considered subsectors (trade, offices, hospitality), especially electrical cross-cutting appliances like VAC, refrigeration, heat pumps, electrical water heating and night storage heaters seem appropriate. The largest potentials can be ascribed to VAC and refrigeration processes.

We used the eLOAD model to calculate the deployment of flexible electricity that could be provided by flexible appliances in the service sector. The modelled deployment is market-based and supported by modelled price signals from a spot market. Other (mainly grid-based) incentive systems, and possible future incentives for flexible behaviour, such as variable grid tariffs, are neglected in this study, even though they could offer higher potential revenues. Since the service sector is not present on any of the potential flexibility markets, the analysed case in this study serves to provide insights into the available and usefully deployable amount of flexibility in this demand-side sector. We distinguished between technically and practically deployed flexibility. Technical deployment refers to the case where all flexible appliances participate in DR; practical deployment refers to the share of companies willing to provide their appliances for DR purposes (first-movers). The main results are summarized in Table VI-12. The *technical calculations* resulted in about 7.74 TWh of electricity shifted to smooth the residual load curve. The technical deployment of flexibility thus amounts to around 35% of the overall consumption of flexible appliances in the selected subsectors of the service sector (about 22 TWh), i.e. the theoretical potential in our scenario. This is due to the fact that not all the flexibility is necessary or available to smooth the residual load in every hour of the year. The same applies to the RES surplus reduction. Technically, renewable surplus electricity can be reduced by 510 GWh per year: Although there is a RES surplus of 2.5 TWh and a practical flexibility deployment of 7.74 TWh, it is not possible to reduce all the RES surplus. RES surplus often occurs with high peaks which cannot be absorbed by our selected sectors alone, or the duration of RES surplus is too long, so that a shift from hours without surplus to hours when surplus occurs is hardly possible. A higher share of RES could thus create more opportunities to integrate the flexibility potentials; our calculations for the 80% RES scenario result in 1.63 TWh.

When considering the willingness to participate, our *practical calculations* resulted in 1.82 TWh flexibility deployment and 131 GWh reduction of renewable surplus electricity with the first-movers.

Table VI-12: Overview of main results of the 50% (resp. 80%) RES scenario (TWh)

Consumption of flexible appliances	**Technical flexibility deployment**	**Practical flexibility deployment**	**Technical reduction of RES surplus**
22.09	7.74	1.82	0.51 1.63 (80% RES share)

In another study (Wohlfarth et al., tbp), the same consumption data (theoretical potential) were used to estimate flexibility potentials that could be provided by the sector (irrespective whether or not they can be deployed at the point of time of availability). The technical potential, e.g. for VAC, resulted in 1/6 of the technical flexibility deployment (Table VI-12), assuming one hour of load shifting on 30 days in summer, and in half of the technical flexibility deployment for refrigeration, assuming 2 hours of load shifting each day of the year. Compared to these estimations, our results show an average of 6 hours of daily load shifting for VAC (in sum on 30 days in summer) and 4 hours of daily load shifting for refrigeration appliances to smooth the residual load. This indicates that the actual technical feasibility of flexibilisation (i.e. frequency and duration of loadshift parameters for appliances) needs further research, especially with respect to aspects of comfort.

In the conducted survey, we asked about the future potentials of DR. The participants were asked if they could imagine load management that automatically adjusts the consumption of their appliances assuming there were no additional costs for the control technologies. This question is naturally hypothetical and the answers are given based on current (e.g. technical and regulatory) experiences. If these circumstances and the incentives to participate improved in the future and such measures were better known, the willingness to provide flexible loads might be much higher. Regarding the willing share of companies, small companies with less than 10 employees dominate the results, because most companies in Germany fall under the category of small enterprises. Furthermore, the willingness to conduct DR is asymmetric: Compared to small companies, large companies are more willing, have higher energy consumption and are most likely our primary target group. The large enterprises in the service sector could function as role models for the subsequent broader rollout of DR. However, considering the willingness of possible participants in DR gives additional insights compared to exploring potentials based on only technical assumptions. Current research either does not consider the willingness of the service sector to provide flexibility or determines this based on simple assumptions.

Regarding the economic benefit of flexibility provision, our assumptions are comparable to the exploitation of spot market price spreads in a real-time price-based electricity tariff. The results related to a future higher share of RES depend heavily on the development of price spreads. We did not consider economic potentials in other flexibility markets like the balancing market, because they are mostly inaccessible or unattractive – especially to the small companies that make up a large part of the service sector. A further development of these markets, easier access and an extension of the aggregator model could help to tap flexibility potentials, raise acceptance and reduce the required organisational efforts.

The modelling of flexible loads could be extended to include other markets. In this case, the market could be chosen to match the load patterns and the availability of flexibility. So far, the decision to conduct a DR measure is modelled in eLOAD based on the spot market electricity price only. The model would need to be extended, e.g. by introducing commodity and capacity prices of the reserve markets.

Furthermore, incentive-based DR programmes also exist, such as direct load control or power cut-offs. In the eLOAD model, these programmes are only considered for industrial processes at the moment, such as primary aluminium production. Developing these options for smaller flexible loads would allow an even more holistic assessment of the potential benefits from DR and of the impact of additional DR programmes on process load adjustment and residual load smoothing.

Complementary to the energy quantities (MWh), the load peaks (MW) could be taken into account to evaluate a load-shifting potential. Their additional value comes from levelling and compensating peak loads, while our focus was on smoothing the residual load and integrating renewable energies.

5 Conclusions

Overall, we gained valuable insights into the current and future state of DR activities through a market research survey in the German service sector. These insights were used to improve the representation of the available flexible technologies in a DR model (eLOAD).

The main conclusions of our study are summarized as follows:

i. The share of companies conducting DR measures in the service sector is currently small (about 4%), but the share of companies willing to participate is more than four times as high as this (16.5%).

ii. The technical flexibility deployment for our selected subsectors is estimated at 7.74 TWh per year, which is around 35% of the theoretical DR potential (the consumption of flexible appliances) because only a smaller share is technically available for flexible use and not always available when required.

iii. The modelling resulted in reducing the renewable surplus electricity per year by about 510 GWh with a 50% RES share and 1.63 TWh with an 80% RES share.

iv. The willingness to contribute to DR in the service sector needs to be considered. The share of willing companies can be seen as first-movers able to kick-start a trend to tap a large share of the technically available potential in the future.

Further research could include the modelling of other flexibility markets such as the balancing markets and additional DR measures. These options could increase the financial benefits of DR for companies. The effect of potential financial gains on the companies' willingness to participate in DR should also be analysed in detail.

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Chapter VII

How much load flexibility can a euro buy?

Findings from a choice experiments with companies in the German commerce and services sector

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Abstract

Demand-side load management is considered a cost-efficient solution for accommodating growing shares of intermittent renewable electricity production. Here, we use double-bounded dichotomous choice (DBDC) contingent valuation (CV) to estimate the effectiveness of a subsidy for companies to make available their HVAC and cooling systems for automated load management. Our sample includes 1131 companies in the German commerce and services sector with ≥10 employees of which we elicit the willingness to accept (WTA) automated load management in exchange for an annual subsidy payment. To our knowledge, our study is the first CV study on load management among companies.

1 Introduction

Demand-side load management is considered a key and cost-efficient strategy to help integrate fluctuating renewable energy sources into the electricity system and thus to meet climate and energy security targets in many countries (e.g. Barton et al. 2013; Siano 2014). For example, the energy "Winter Package" proposed by the European Commission in 2016 also highlights the importance of load management while generally foreseeing a more active role for consumers to play in the future electricity market (EC COM(2016) 864 final 2). The value of load management will be particularly high at times when the feed-in from renewables is low while electricity demand is high, and when the feed-in from renewables is high but electricity demand is low. Load flexibility potentials may be offered at the spot or the balancing markets. Special importance is also given to the building sector, where users should be encouraged to use ICT and smart technologies to ensure an efficient operation of the building (EC COM(2016) 765 final).

Supply of such flexible loads may be incentivized via time-of-use (TOU) pricing, i.e. dynamic pricing, real time pricing or critical peak pricing (CPP). With CPP, customers receive prior notice when they will face particularly high prices during certain times of some days. Thus, CPP provides particular incentives to shift loads. TOU pricing involves voluntary demand responses and has mostly been studied for the residential sector[1]. In contrast, with controllable demand response such as direct load control and interruptible load programs, customers allow their system operator to automatically curtail their electricity demand under certain, pre-specified conditions. For example, to support the German energy transition (*Energiewende*), which foresees an 80% share of renewable energy sources in the power mix by 2050, the recent Ordinance on Agreements on Sheddable Loads (Sheddable Loads Act, AbLaV 2016) incentivizes electricity consumers to offer their flexible loads.[2] To qualify, providers of flexible loads have to comply with certain requirements such as a prequalification of the flexible appliances and minimum bids. Thus, only large companies are currently offering loads under this ordinance. While TOU pricing primarily affects the wholesale spot market, load management primarily affects the balancing market.

Several engineering-economic studies have assessed the technical potential for load shift in Germany, thereby typically focusing on electricity-intensive production processes in large manufacturing (e.g. Dena 2010; Apel 2012; Klobasa et al., 2013a; Ausfelder et al. 2018). The findings suggest that these companies may provide flexible loads of up to ca 5 GW, corresponding to ca. 2.5 percent of total installed electricity generation capacity in Germany. Few studies have explored the technical flexibility potential in the commerce and

1 For an overview see Faruqui and Sergici (2010). The empirical studies analyzing the response of industrial and small commercial electricity usages to TOU pricing include Hirshberg and Aigner (1983), Jessoe and Rapson (2014), Faruqui et al. (2015), and Qiu et al. (2018).

2 Accordingly, industrial electricity consumers may receive €500 per MW per day and €400 per MWh offered.

services sector, which contributes to 29% to the electricity consumption in Germany (AGEB, 2015)[3]. While production processes determine the flexibility potential in the industrial sector, cross-sectional technologies define the load flexibility potential in commerce and services sector. Ventilation, air-conditioning and cooling/freezing services appear to offer the largest potentials for load management (Klobasa 2007; Apel 2012; Gils 2014). So far though, only a small fraction of these technical potentials is realized. Barriers to realization include inadequate regulation (e.g. Rüster et al., 2014), and, especially for the manufacturing sector, the perceived risk of disruption of production operations, negative impacts on product quality, investment costs, and uncertainty about cost savings (Olsthoorn et al. 2015).

For load flexibility from cross-cutting ancillary technologies or for cooling/freezing services, little is known about the potential, its responsiveness to financial incentives, or to particular design features of controllable demand response contracts. Also, no study has yet explored the factors explaining heterogeneity in company response to incentive payments. Aiming to fill this gap, this paper explores the required financial incentives to promote flexibility measures, and how these incentives relate to duration and to the frequency of the measure, whether it can be activated any time or only during agreed-upon times, and how the required incentives vary with company characteristics such as experience with load shift. The flexibility measures considered provide ventilation, air-conditioning, cooling and freezing services in the commerce and services sector.

Methodologically, our empirical analysis relies on contingent valuation choice experiments carried out in a survey of nearly 1600 companies in Germany in 2017. With the large and fast-growing share of renewable electricity resulting from its *Energiewende*, realizing cost-efficient load flexibility potentials is particularly relevant in Germany (Müller and Möst, 2018). Respondents' choices are used to estimate (for each technology) the probability that companies participate in the proposed load shift measure as a function of the subsidy offered, and to construct curves for the specific subsidy costs – i.e. the costs of load shift (in €/MWh). Further simulations explore the potential of these load shift measures for Germany. Our estimates for the subsidies required to offer demand flexibility are also compared to the prices at the balancing markets, and to the costs of other flexibility options such as battery systems. Thus, our findings are expected to provide tentative guidance for designing efficient controllable demand response programs and to contribute to an overall cost-efficient supply of flexibility options.

The remainder of the paper is organized as follows. Section 2 presents the methodology, describing an analytical model to evaluate the effectiveness of a subsidy policy, the company survey, and the choice experiment. Section 3 presents the results, showing findings for

3 The German energy balances partitions final energy consumption into four end-use sectors: industry, private households, transportation, and the combined commerce and services sector.

subsidy levels across technologies and for the determinants of the subsidy level. Section 3 also includes simulation analyses on the efficiency of subsidies across technologies and compares findings with prices on the markets for flexibility. Finally, section 4 summarizes and discusses our main findings and identifies policy implications.

2 Methodology

In this section, we first present a simple analytical model for evaluating the effectiveness of a subsidy payment for load shift/curtailment in firms. Then, we describe our survey, the choice experiment, and the econometric model that we employed to estimate the subsidy level and to conduct simulations. Finally, we present the data by including the descriptive statistics of the choice experiment and the firm characteristics used as covariates in our econometric model.

2.1 Analytical model of subsidy effectiveness

The model presented in this section will be parameterized with econometric estimates based on a contingent valuation survey and from information on participants' load flexibility measures elicited from the survey and the literature. Specific cost curves will then be constructed as a function of the subsidy level, which allows simulating the effects of a subsidy/controllable demand response program for various load shift measures (here: ventilation, air conditioning, cooling and freezing).

For a particular measure, the specific payment c are the subsidy level S per average load shift Δl (curtailment) per adopted measure

(1) $$c = \frac{S}{\Delta l}$$

The total expenditure for payments C is then

(2) $$C = N_{adopt} \times S$$

where N_{adopt} is the total number of firms adopting a particular load management measure if S > 0. N_{adopt} = 0 if S = 0, i.e. we assume that firms would not implement those measures if there was no subsidy payment. This also means that there is no free riding.

We denote the number of adopters as:

(3) $$N_{adopt}(S) = N_{pop} \times b(S), \text{ for } S > 0$$

Where N_{pop} stands for the population of firms, and $b(S)$ is the probability of adoption, i.e. Pr(adoption | S); $b(S)$ is a function of the subsidy S with $b'(S) > 0$ (for $S > 0$).

Total program costs are then:

(4) $$C = N_{pop} \times b(S) \times S$$

The load shift potential by all adopters ΔL can be written as:

(5) $$\Delta L = b(S) \times N_{pop} \times \Delta l$$

Note that dividing total costs C, i.e. equation (4), by the total load shifted via the subsidy program ΔL, i.e. equation (5) yields specific subsidy costs c, i.e. equation (1).

As further detailed in section 2.4., we employ a double-bounded willingness-to-accept choice experiment and interval data model estimation to predict the probability of adoption and to estimate $b(S)$.

2.2 Survey

A standardized quantitative survey on companies of the German commerce and service sector was conducted between May and July 2017, with the help of a market research institute (Gesellschaft für Konsumforschung, GfK). Our focus was on companies from the subsectors displayed in Table VII-1. These account for more than 50% of electricity consumption of the commerce and services sector (Schlomann et al, 2015). In addition, these subsectors avail of large shares of flexible cross-sectional appliances. A total of 1587 companies completed the survey. We made sure to achieve at least 100 responses in each of the subsectors office-type firms, retail/wholesale, and hospitality. Sampling prioritized medium-size and large companies because we expect larger firms to possess most load management potential.

The interviews took about 30 minutes and were conducted with the person in charge of energy issues at each company by trained interviewers via computer assisted telephone interviews (CATI). The items of the survey covered, among others, companies' characteristics, experiences with load management, perception and readiness towards load management, technical information on availability of flexibility options and a hypothetical choice experiment to elicit participants' willingness to participate in a controllable load management program for varying subsidy payments. Before leading the participants to the choice experiment, more general questions about electricity consumption and appliances were asked.

The survey also included a question to rate participating companies' willingness to implement automated load management. Only participants who expressed some willingness to implement (a rating between "maybe" and "definitely yes") were asked to participate in the choice experiment. This left us with 342 companies considered to be "in the market" for automated load management and to respond, with increased probability, from an informed position.

Table VII-1 shows the structure of our subsample of interested companies compared to the total of Germany. The numbers show that companies from the sectors trade with food and companies including restaurants are overrepresented in our subsample compared to the distribution of companies in Germany.

Table VII-1: Structure of the subsample in comparison the total in Germany

Sector	**Number of employees**	**Companies in subsample**	**Share within Subsectors**	**Compa-nies in Germany (2015)**	**Share within Subsector**	**Share in subsample**	**Share in Germany**
Office-type	1 - 9	16	13.6%	1,061,984	93.5%	34.5%	60.3%
	10 - 49	42	35.6%	54,678	4.8%		
	≥ 50	60	50.8%	19,024	1.7%		
Retail food	1 - 9	3	7.9%	60,190	89.7%	11.1%	3.6%
	10 - 49	22	57.9%	5,844	8.7%		
	≥ 50	13	34.2%	1,074	1.6%		
Retail Non-Food	1 - 9	11	36.7%	298,214	92.3%	8.8%	17.2%
	10 - 49	11	36.7%	21,623	6.7%		
	≥ 50	8	26.7%	3,375	1.0%		
Wholesale Food	1 - 9	2	13.3%	17,296	81.7%	4.4%	1.1%
	10 - 49	6	40.0%	3,053	14.4%		
	≥ 50	7	46.7%	831	3.9%		
Wholesale Non-Food	1 - 9	4	14.3%	72,190	79.5%	8.2%	4.8%
	10 - 49	8	28.6%	14,334	15.8%		
	≥ 50	16	57.1%	4,306	4.7%		
Hotel with restaurant	1 - 9	10	20.8%	26,986	86.2%	14.0%	1.7%
	10 - 49	28	58.3%	3,520	11.2%		
	≥ 50	10	20.8%	805	2.6%		
Hotel without restaurant	1 - 9	2	28.6%	16,002	88.1%	2.0%	1.0%
	10 - 49	5	71.4%	2,060	11.3%		
	≥ 50	0	0.0%	103	0.6%		
Restau-rants	1 - 9	19	32.8%	185,215	95.1%	17.0%	10.3%
	10 - 49	27	46.6%	8,508	4.4%		
	≥ 50	12	20.7%	1,018	0.5%		
Total		342		1,882,233			

We excluded the smallest category of companies (1-9 employees) from our analyses, because they are considered to have relatively low potential. This improves representation but reduces the subsample to 275 companies.

2.3 Choice experiment

With the subsample of 275 firms, we conducted a choice experiment on automated load management. Each company was asked to answer choice questions regarding two randomly selected technologies from a set of six with potential flexibility: ventilation, air conditioning, refrigeration, freezing, heat pump, cogeneration. If a company did not avail of a selected technology, the observation was recorded as missing.

Table VII-2 shows how many of the eligible companies responded by technology. Of the 275 eligible companies, 34 did not have any of the two randomly selected technologies and 112 availed of only one of the two. Very few companies appeared to have a heat pump or a cogeneration installation. The small number prohibits application of econometric analysis to those two technologies, which is why they are excluded from our analyses. That leaves us with 237 companies that participated in the choice experiment for at least one of four technologies: ventilation, air conditioning, cooling, and freezing.

Table VII-2: Distribution of eligible, responding companies across combinations of technologies

	2nd technology						
1st technology	**Air con-ditioning**	**Refrige-ration**	**Freezing**	**Heat pump**	**Cogene-ration**	**None**	**Total**
Ventilation	46	32	11	1	5	18	113
Air conditioning	0	15	6	2	5	50	78
Refrigeration	0	0	34	0	5	6	45
Freezing	0	0	0	0	1	0	1
Heat pumps	0	0	0	0	0	1	1
Cogeneration	0	0	0	0	0	3	3
None	0	0	0	0	0	34	34
Total	46	47	51	3	16	112	275

For each type of measure the structure of our choice experiment questions is outlined in Figure VII-1. The choice experiment design is similar to Alberini and Bigano (2015) and Olsthoorn et al. (2017) to analyze rebates and free riding, respectively, in the context of heating system replacement by private households.

The experiment part of the survey first described a hypothetical load curtailment measure. Respondents were asked to imagine that one of the six energy-using technologies, say the ventilation system, was switched off regularly for a certain period of time. In return the respondents would receive a yearly compensation payment from their electricity provider. To this end, the ventilation system would be equipped with control technology enabling external controlling of the ventilation system. The participating firms were informed that they would not have to bear any of the costs for these control technologies. They were further told that all air quality standards (or equivalent for other applications) would be

met, but that tolerance levels would be exploited more flexibly. The firms were assured that, in case of need, they would be able to take back control over their systems at any time. In this case, compensation payment would be adjusted downward pro rata. The subsidy is therefore assumed to reflect respondents' perceived net costs of shifting these loads.

To contain a potential hypothetical bias, we used a cheap talk design. Prior to making their choices, respondents were told that people in general respond differently when asked to make hypothetical choices. They were asked to put themselves into the situation of their firm when answering to the subsequent questions.

The choice experiment proposed a load curtailment measure which was characterized by a given *frequency* and a given *duration* in addition to a given annual *payment*. *Frequency* referred to the number of times (per day or week) the measure would be implemented. *Duration* referred to the length (in minutes) the measure would be effective if implemented. In addition, any load curtailment was either restricted to agreed time slots only or could be activated any time.[4] Table VII-3 shows the levels of the attribute for each application.

Table VII-3: Attribute levels by application

Attribute	**Ventilation**	**Air conditioning**	**Refrigeration**	**Freezing**
Payment (Euros)	250/500/1000/ 1500/2500	250/500/1000/ 1500/2500	500/1000/2000/ 4000/8000	500/1000/2000/ 4000/8000
Frequency	2 times daily / daily / weekly			
Duration (minutes)	30 / 60 / 90			
Time constraint	Can be activated any time / at agreed time slots only			

Since data on the costs of providing flexibility is not available for these measures, they had to be estimated. Regarding the payments, we based our assumption on the findings of a study on load management in the German industry (Klobasa et al., 2013b). Accordingly, to participate in load management measures, companies expect incentive payments corresponding to about 15% of their annual electricity costs. To transfer these findings to our case, we estimated the share of electricity costs of each appliance using the data available on energy consumption of the tertiary sector (Schlomann et al., 2015). For the technologies considered in our study, this resulted in incentive payments ranging between 5% and 25% of the annual electricity costs for the companies considered.

Besides the subsidy, the duration and the frequency of the load curtailment were chosen as additional attributes of the proposition. We expected both attributes to have an influence on the willingness to accept. the required payment to use the specific appliance for load management. Both attributes influence the degree to which the load management affects

4 These attributes were identified in the literature as being relevant features of load management options (e.g. Klobasa et al. 2013b).

the regular operation of the appliance as well as the value of the appliance for load management measures in general, being a proxy for the share of shiftable electricity. The fourth attribute concerned the absence or presence of a constraint on the times load management actions would be allowed. This attribute varies the potential surprise factor and thus the risk on the part of the company. These attribute levels result in 18 different load management propositions (treatments).

Each respondent was shown, at random, a first proposition S1 and could either accept or reject it. In a follow up question, respondents who rejected the initial proposition were offered a second proposition S2, where the initial subsidy payment was doubled. Similarly, respondents who accepted the initial proposal were offered a second proposition, where the initial subsidy payment was halved. The levels for *duration* and *frequency* and the *time constraint* were the same in both propositions. Since the values for the levels of the subsidy, frequency, duration, and the time constraint were all randomly assigned to respondents, our design mimics a randomized controlled experiment.

The choice options yielded four types of respondents:

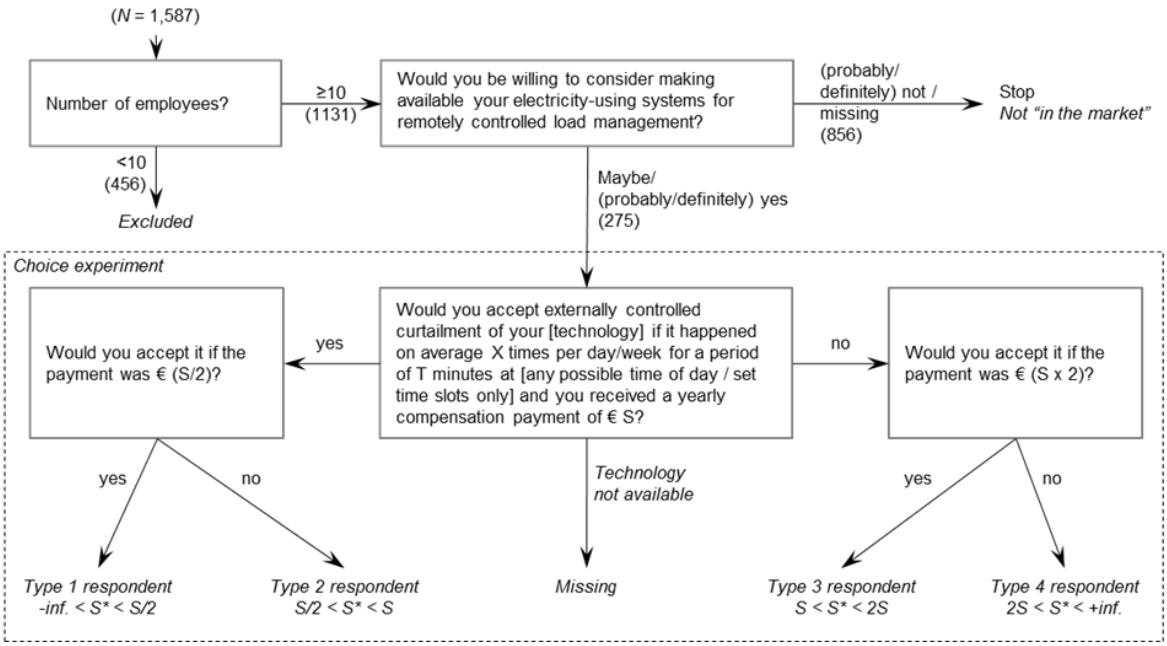
Type 1: Respondents who accepted both the initial and the second proposition. For this type of respondent, the latent reservation incentive is between $-\infty$ and S2 (= ½ S1).

Type 2: Respondents who accepted the initial proposition but rejected when the subsidy was halved. For this type of respondent, the latent reservation incentive is between S1 and S2 (= ½ S1).

Type 3: Respondents who rejected the initial proposition but accepted when the subsidy was doubled. For this type of respondent, the latent reservation incentive is between S1 and S2 (= 2 S1).

Type 4: Respondents who rejected both the initial and the second proposition. For this type of respondent, the latent reservation incentive is between S2 (= 2 S1) and ∞.

Figure VII-1: Structure of the choice experiment questions



2.4 Econometric model

We use an adapted double-bounded willingness-to-pay approach (Cameron and James 1986; Hanemann et al. 1991) to estimate the probability of adopting a load management measure as a function of the subsidy offered. Similar to Alberini and Bigano (2015) and Olsthoorn et al. (2017), the adaptation reflects a focus on willingness-to-accept a subsidy rather than on willingness-to-pay and a follow-up subsidy question with a halved or doubled subsidy, depending on whether the first subsidy was accepted or rejected, respectively (e.g. Cameron and Quiggin 1994).

We assume that a firm (represented by the survey participant) *i* has a reservation subsidy level S_i^*. A subsidy $S_i \geq S_i^*$ would lead a firm to adopt the proposed load management measure; a subsidy $S_i < S_i^*$ would lead to rejection. S_i^* is a function of both the load management package and characteristics of the firm. It can be written as:

(9) $$S_i^* = \alpha + \boldsymbol{x}_i\boldsymbol{\beta} + \boldsymbol{z}_i\boldsymbol{\delta} + \varepsilon_i$$

where $\boldsymbol{x}_i$ defines the load management package consisting of the frequency f_i, the duration of the measure t_i, and whether or not load can only be curtailed on agreed-upon time slots; $\boldsymbol{z}_i$ is a set of control variables defining a firm's characteristics; and ε_i is the normally distributed error term with standard deviation σ and an expected value of $E(\varepsilon) = 0$. This means that the model implicitly assumes that respondents know their opportunity costs of the load management measure and that their choices do not suffer from a starting-point (anchoring) bias, i.e. the possibility that respondents adjust their WTA between choices,

anchoring it to the first subsidy level (Herriges and Shogren, 1996).[5] The firm characteristics comprise a firm's stated intention to accept and experience with load management, its size and sector, and, for cooling, specific attributes of the cooling installations. Firm characteristics are described in section 2.5 and Table VII-5.

S_i^* cannot be observed, but it can be estimated in a double-bounded contingent valuation model. The probability that S_i^* lies between the lower (S_i^L) and upper bound (S_i^U) obtained from the respondent's answers in the choice experiment is written as the following interval data model:

$$(10) \quad Pr\left(S_i^L < S_i^* \leq S_i^U\right) = Pr\left(S_i^L < \alpha + \boldsymbol{x}_i\boldsymbol{\beta} + \boldsymbol{z}_i\boldsymbol{\delta} + \varepsilon_i \leq S_i^U\right) =$$

$$Pr\left(\frac{\left(S_i^L - (\alpha + \boldsymbol{x}_i\boldsymbol{\beta} + \boldsymbol{z}_i\boldsymbol{\delta})\right)}{\sigma} < \varepsilon_i/\sigma \leq \frac{\left(S_i^U - (\alpha + \boldsymbol{x}_i\boldsymbol{\beta} + \boldsymbol{z}_i\boldsymbol{\delta})\right)}{\sigma}\right) =$$

$$\Phi\left(\frac{\left(S_i^U - E(S_i^*)\right)}{\sigma}\right) - \Phi\left(\frac{\left(S_i^L - E(S_i^*)\right)}{\sigma}\right) = \Phi^U - \Phi^L$$

where Φ denotes the standard normal cumulative density function, and $E(S_i^*)$ is the expected value of the reservation subsidy level.

For the four types of respondents (Figure VII-1), Φ^U and Φ^L are as follows:

For type 1 respondents, $\Phi^U = \Phi\left(\frac{½\, S1_i - E(S_i^*)}{\sigma}\right)$ and $\Phi^L = \Phi(-\infty) = 0$.

For type 2 respondents, $\Phi^U = \Phi\left(\frac{S1_i - E(S_i^*)}{\sigma}\right)$ and $\Phi^L = \Phi\left(\frac{½\, S1_i - E(S_i^*)}{\sigma}\right)$

For type 3 respondents, $\Phi^U = \Phi\left(\frac{2S1_i - E(S_i^*)}{\sigma}\right)$ and $\Phi^L = \Phi\left(\frac{S1_i - E(S_i^*)}{\sigma}\right)$.

For type 4 respondents, $\Phi^U = \Phi(\infty) = 1$ and $\Phi^L = \Phi\left(\frac{2S1_i - E(S_i^*)}{\sigma}\right)$.

We estimate the coefficients α, $\boldsymbol{\beta}$, and $\boldsymbol{\delta}$ via a maximum likelihood procedure. With these coefficients, we can predict the probability of adoption for the sample.

5 Hanemann et al. (1991) illustrate the efficiency gains obtainable by moving from a single bounded dichotomous choice, thus substantially tightening the confidence interval around the parameter estimates. Efficiency gains of higher order bounded dichotomous choice approaches appear to diminish quickly (Cooper and Hanemann 1995; Scarpa and Bateman, 2000) Prasenjit (2009) shows that for a systematic choice of bid vectors efficiency gains from using a DBDC may outweigh the biases

2.5 Data

In this section, we present the descriptive results of the choice experiment (Table VII-4, Figure VII-2) and the firm characteristics used in our econometric model (Table VII-5).

2.5.1 Choices

Table VII-4 shows that, unlike expected, the likelihood of agreeing to the hypothetical load management proposition does not clearly increase with the level of the subsidy, except for freezing.

Table VII-4: Proportion of "yes" responses by subsidy offered and by load management measure

Subsidy (€)	**Ventilation**	**Air conditioning**	*Subsidy (€)*	**Refrigeration**	**Freezing**
250	64.0	53.6	**500**	59.1	20.0
500	66.7	46.2	**1000**	62.5	45.5
1000	45.5	58.3	**2000**	84.2	50.0
1500	54.6	34.8	**4000**	79.0	68.8
2500	60.0	47.8	**8000**	56.3	75.0
Total	58.0	48.4	**Total**	68.5	57.7
N	*112*	*124*	***N***	*92*	*52*

Figure VII-2 and Figure VII-3 show the distribution of response types. In Figure VII-2, the share of respondents per response type is shown per technology and for all technologies combined when they are stacked. Figure VII-3 shows the distribution of the response types for the 1st technology and for the 2nd technology for those respondents who took the choice experiment for two technologies. The double-bounded approach reveals that those who accepted the first subsidy very likely also accepted the halved subsidy, and, even more so, those who rejected the first subsidy also very likely rejected the doubled subsidy. Similarly, when responding for a 2nd technology, type1 and type 4 respondents tended to repeat the choices they had made for the first technology.

Figure VII-2: Distribution of respondent types by technology

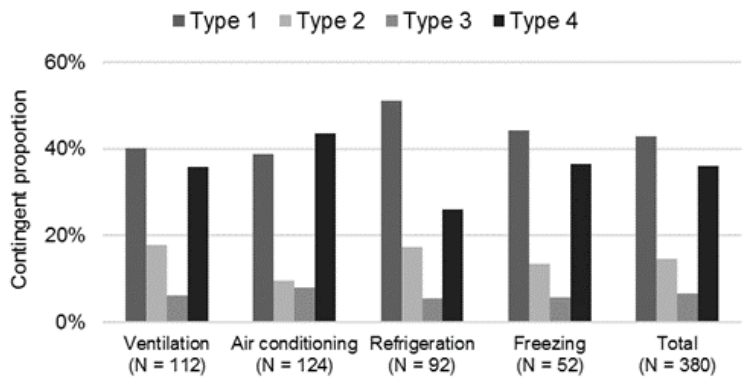
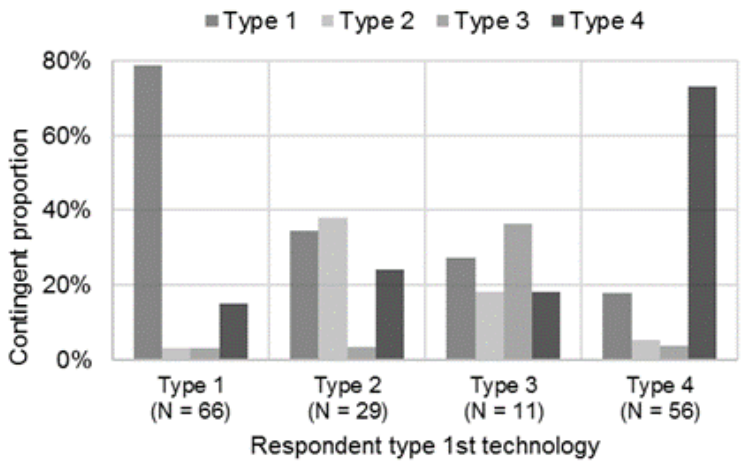


Figure VII-3: Respondents' response type for 2nd technology by response type for 1st technology. Includes only companies who responded to two technologies (N = 162)



2.5.2 Covariates

We test how companies' reservation subsidies depend on the attributes of the load management proposition and on attributes of the companies. Company attributes that we include as covariates are the prior intention to accept and experience with load management, company size and sector, and, for Cooling, specific attributes of the cooling installations.

Stated intention to accept load management. Descriptive results showed a polarized sample whose responses show no clear relation to the subsidy levels. This raises the suspicion that prior beliefs regarding load management may contribute to explaining respondents' WTA. Therefore, we test the role of a firm's intention to accept as stated prior to the experiment, using the same variable based on which we selected the companies that were "in the market." Three levels remain in the variable that reflects observed answers to the question

whether the company would consider automated load management: maybe, probably yes, and definitely yes.

Load management used. To control for experience while testing for the effect of stated intention, we include a dummy variable that takes the value of 1 if the company currently uses load management and 0 otherwise.

Company size. Despite our framing explicitly stating that the company would incur no capital costs, load management involves transaction costs, which in large companies with larger volumes of shiftable consumption may be relatively less important. On the other hand, larger companies have larger systems and thus more potential to offer for which they may incur higher opportunity costs and thus require larger subsidies. We expect that the size effect outweighs the lower transaction costs and, thus, that larger companies have higher reservation subsidies. We control for size by means of the log of the number of the company's employees.

Sector. The importance of the services that the technologies included in this study deliver may vary by sector. For example, client comfort may be essential in the hospitality sector and offices, but maybe less so in trade, which may influence the willingness to accept flexibilization of HVAC systems. We include three sector dummies, for office-type firms, trade (wholesale/retail), and hospitality.

Attributes of cooling appliances. The willingness to make cooling installations available for load management may depend on the attributes of the cooling systems in use. If the number of cooling installations is large, chances are that there is one or more that are less crucial and allow for flexibility. Also, the temperature may matter. On the one hand, temperatures below freezing may offer more bandwidth to exploit (freezing is freezing?). On the other hand, flexibility may be lower because freezing requires more energy and incites to freeze no more than necessary; besides, deeper freezing means steeper temperature gradients when load is reduced. Therefore, for cooling (i.e., refrigeration and freezing), we include three attributes of the cooling systems. We control for the number of cooling appliances, the average temperature (°C) in the cooling appliances (fridges and freezers), and the average temperature (°C) in cold storage installations.

In Table VII-5, we list the descriptive statistics of all covariates used, using the subsample of 275 firms that qualified for the choice experiment.

Table VII-5: Covariates: descriptive statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Stated intention					
Maybe	275	0.498	0.501	0	1
Probably yes	275	0.313	0.464	0	1
Definitely yes	275	0.189	0.392	0	1
Load management used	206	0.252	0.435	0	1
Employees	264	336	1444	10	20000
Ln(Employees)	264	4.075	1.520	2.303	9.903
Sector					
Office-type	275	0.371	0.484	0	1
Wholesale/retail	275	0.331	0.471	0	1
Hospitality	275	0.298	0.458	0	1
Number of cooling appliances	81	10.83	17.83	0	150
Average T(deg. C) in cooling appliances	79	4.620	6.300	-20	23
Average T(deg. C) in cold stores	103	3.184	6.709	-22	20

3 Results

We first present our econometric findings on expected mean and median subsidy levels per technology. To increase the degrees of freedom, we then aggregate the results for similar technologies and identical attribute levels. Ventilation and air conditioning are combined and labeled *HVAC*. We also aggregate refrigeration and freezing and label it *Cooling*. For these two amalgamated technology classes, we present results of constant-only models alongside estimations for models including the attributes of the load management measure and company characteristics.

3.1 Econometric results for reservation subsidy levels

Table VII-6 shows the estimated mean and median reservation subsidy level for the four technologies ventilation, air conditioning, refrigeration, and freezing. The constants represent the expected mean and median reservation subsidies, and the sigma represents the standard deviations of the reservation subsidies, assuming they follow a normal distribution.

Table VII-6: Results of the maximum likelihood estimations of the constant-only model for four technologies

	Ventilation	Air conditioning	Refrigeration	Freezing
Constant	1186*** (0.002)	1668*** (0.001)	244 (0.853)	2971** (0.036)
Sigma	3465*** (0.000)	4581*** (0.000)	9969*** (0.000)	8574*** (0.000)
Observations	112	124	92	52
Log-likelihood	-157.25	-151.17	-130.40	-57.09

p-values in parentheses.
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

For ventilation, we find that for a subsidy of €1186, 50% of the companies represented by the sample would agree to a load management measure. However, the spread is considerable as per the standard deviation of €3465. For air conditioning the estimated mean subsidy is €1668 with a standard deviation of €4581. For refrigeration we find the lowest expected mean subsidy at €244, but with a large standard deviation of almost €10,000. For freezing the expected mean subsidy is highest at close to €3000 and the spread is large with sigma estimated at €8574. The large spreads result from the polarized positions in the sample as shown in Figure VII-4. In addition, the larger spread for refrigeration and freezing may result from the larger range of subsidy levels proposed in the choice experiment.

3.2 Econometric results for determinants of the reservation subsidy

3.2.1 HVAC

Table VII-7 reports the results of the maximum likelihood estimates of companies' WTA for HVAC systems, using various model specifications. The first panel contains the results for a constant-only model, where the constant is the expected mean and median reservation subsidy. As expected, at €1407 this is in between the separate estimates for ventilation and air conditioning reported in section 3.1, Table VII-6. The standard deviation is nearly €4000, estimating a substantial share of companies with negative reservation subsidies. The second model controls for technology and shows that for air conditioning the median subsidy is estimated almost €500 higher than for ventilation, which is consistent with the difference in Table VII 2, but the difference is not statistically significant.

The third panel reports the relationships between the reservation and the attributes of the load management measure. We see no statistically significant effect of the frequency or duration of load curtailment. The time constraint treatment, however, appears to affect the

WTA, where a limitation of the time of day that curtailment is allowed carries an estimated worth of €1737.

The fourth panel adds stated intention and experience. It shows how, controlling for current use, WTA strongly relates to a company's stated intention to accept load management. Stronger intentions to accept are associated with considerably lower reservation subsidies. At the same time, it cannot be said that experience leads to acceptance, as companies who currently use load management tend to require higher subsidies for acceptance. Here, a caveat is that we do not know which systems are currently subject to load management and whether HVAC systems are concerned.

Finally, in the fifth panel, we include company size and sector and do not find that either is significantly related to WTA.

Table VII-7: Results of the maximum likelihood estimations for ventilation and air conditioning services

	HVAC					
Variables	(1)	(2)	(3)	(4)	(5)	(6)
Technology						
Ventilation		(base)				
Air conditioning		477.8				
		(0.429)				
Attributes						
Frequency (#/week)			19.32	42.00	31.22	31.53
			(0.727)	(0.466)	(0.573)	(0.571)
Duration (min)			-3.799	-6.296	-4.978	-5.198
			(0.751)	(0.622)	(0.676)	(0.665)
Only on predefined time slots			-1737***	-1359**	-1854***	-1859***
			(0.004)	(0.031)	(0.002)	(0.002)
Stated intention						
Maybe				(base)		
Probably yes				-1677**		
				(0.029)		
Definitely yes				-2756***		
				(0.002)		
Load management used				1535**		
				(0.044)		
Ln(Employees)					-65.39	-64.61
					(0.736)	(0.748)
Sector						
Office-type						(base)
Wholesale/retail						101.6
						(0.881)
Hospitality						53.44
						(0.945)
Constant	1407***	1159***	2353**	2572**	2573**	2535*
	(0.000)	(0.008)	(0.014)	(0.014)	(0.040)	(0.056)
Sigma	3981***	3976***	3841***	3502***	3760***	3761***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	236	236	236	183	227	227
Log-likelihood	-309.4	-309.1	-304.9	-231.8	-294.9	-294.9
Chi^2		0.624	8.498**	16.06**	10.05**	10.07
Prob > Chi^2		0.429	0.037	0.013	0.040	0.122
p-values in parentheses	*** p < 0.01, ** p < 0.05, * p < 0.1					

3.2.2 Cooling

Table VII-8 reports the results of the maximum likelihood estimates of companies' WTA for cooling systems and its relation to select covariates. Again, the first panel contains the results for a constant-only model and shows that the expected mean and median reservation subsidy is €1250, with the standard deviation approaching €10,000. This result is in between the separate and disparate estimates for refrigeration and freezing reported in section 3.1, Table VII-6. Controlling for technology in panel 2, we find that for freezing the median subsidy is estimated €2500 higher than for refrigeration, which is approximately equal to the difference in Table VII 6, but the difference is not statistically significant. In panel 3, we add the attributes of the load management measure, for none of which we find a statistically significant association with the reservation subsidy. Other than for HVAC functions, for cooling, the time of day at which load is curtailed does not appear to be of any concern. An explanation may be that cooling is a largely continuous function and much less likely to be subject to a daily cycle such as HVAC. HVAC systems directly affect the comfort of a company's workers and clients and companies are thus likely to have much less tolerance for variation during operating hours.

The fourth panel adds stated intention and experience. As we found for HVAC, for cooling, too, WTA strongly relates to a company's stated intention to accept load management. Favorable intentions are associated with much lower reservation subsidies than a more neutral or reserved position. Again, as for HVAC, here, too, participating companies who currently use load management (on any system) tend to require higher subsidies for acceptance, but the evidence is not statistically significant.

Panel 5 shows that larger companies require higher subsidies; a 1% increase in company size is expected to increase the reservation subsidy by €13. This result supports our expectation that larger companies weigh the subsidy against larger loads and opportunity costs than smaller firms and that this size effect outweighs any transaction cost advantage larger firms may enjoy. Still, specific subsidy costs (per MWh) are expected to be lower for larger firms, due to economies of scale in transaction costs.

In panel 6 sector dummies are added, none of which exhibit a statistically significant effect. The signs, however, are plausible. Cooling is probably closer to the core business in the trade and hospitality sectors, therefore suggesting higher business risk associated with flexibility.

In the last panel, we see that the attributes of the cooling systems do not relate to WTA in a statistically significant way. The lack of statistical significance of the coefficients for the number of cooling appliances and the temperature of cold storage could be partly attributable to a lack of degrees of freedom. Their signs seem consistent with expectations, though: a larger number of appliances would associate with lower subsidies, and colder cold storage would decrease WTA. The latter is consistent with the idea that deeper freezing is associated with less tolerance and/or more sensitivity to load reduction.

Table VII-8: Results of the maximum likelihood estimation for refrigeration and freezing services

				Cooling			
Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Technology							
Refrigeration		(base)					
Freezing		2524					
		(0.200)					
Attributes							
Frequency (#/week)			-19.90	185.8	88.81	104.0	-40.24
			(0.918)	(0.362)	(0.620)	(0.563)	(0.857)
Duration (min)			11.72	-0.29	-7.76	-8.23	15.35
			(0.769)	(0.995)	(0.832)	(0.822)	(0.725)
Only on predefined time slots			1536	350.6	269.1	211.0	1882
			(0.421)	(0.862)	(0.878)	(0.904)	(0.396)
Stated intention							
Maybe				(base)			
Probably yes				-7177***			
				(0.004)			
Definitely yes				-5183**			
				(0.047)			
Load management used				2665			
				(0.205)			
Ln(Employees)					1267**	1344**	
					(0.046)	(0.049)	
Sector							
Office-type						(base)	
Wholesale/retail						3365	
						(0.413)	
Hospitality						2899	
						(0.481)	
Number of cooling appliances							-60.56
							(0.393)
Average T(deg. C) in cooling appliances							-4.809
							(0.979)
Average T(deg. C) in cold stores							-250.1
							(0.183)
Constant	1250	367.5	-165.4	2606	-4382	-7644	1093
	(0.205)	(0.765)	(0.957)	(0.423)	(0.238)	(0.192)	(0.753)
Sigma	9618***	9531***	9578***	8422***	8501***	8476***	8254***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	144	144	144	113	137	137	83
Log-likelihood	-188.4	-187.6	-188.1	-139.9	-173.6	-173.2	-111.7
Chi^2		1.646	0.714	10.47	4.267	4.863	2.979
Prob > Chi^2		0.200	0.870	0.106	0.371	0.561	0.811

p-values in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

3.3 Subsidy effectiveness simulations

Based on our estimate of the subsidy required to have companies realize the flexibility measures, we calculate the annual flexible volume as a function of the subsidy per technology, using the analytical model described in 2.1. We restrict the simulations to ventilation and air conditioning for which we hold our estimates to be most robust.

To do so, we first determine the number of companies within the target sectors (see Table VII-1) which the choice experiment's subsample can be assumed to represent (N_{pop}). In Table VII-9, we combine the sample selections from Figure VII-1 with the population numbers from Table VII-1 and estimate that the 275 companies in our subsample of firms with 10 or more employees that are "in the market" scale to 35,051 German companies in total.

Table VII-9: Extrapolation factor for the simulations

Quantity	Symbol	Number
Number of firms in included sectors in Germany	N_{all}	1,882,233
…with 10 or more employees	$N_{all,\geq 10}$	144,156
Number of firms in sample with 10 or more employees	$N_{obs,\geq 10}$	1,131
Number of firms qualifying for choice experiment	N_{exp}	275
Represented population: potentially adopting firms in target sectors with ≥10 employees	$N_{pop} = \frac{N_{exp}}{N_{obs,\geq 10}} \times N_{all,\geq 10}$	35,051

Next, we estimate Δl, the companies' average load flexibility potential per technology based on participants' responses in the survey. We used the answers given in our survey regarding the availability of technologies to calculate the average of energy consumption caused by each flexible technology used in our choice-experiment (ventilation, air conditioning, cooling and freezing). Using the ratio of flexible energy on the electricity demand for each technology presented in Klobasa (2007), we derived the shares of flexible consumption of each technology to calculate the average of flexible electricity demand for each technology per company of our subsample. Hence, for Δl for technology j we have

$$(11) \quad \Delta l_j = \frac{1}{N} \sum_{i=1}^{N} E_{ij} \times \varphi_j,$$

where E_{ij} is the energy consumption of technology j in company i, and φ_j is the share of flexible energy consumption of technology j from Klobasa (2007). Table VII-10 shows the average potentials for the medium category of attributes presented in the choice experiment (i.e. use of flexible load for 60 minutes per day). We assumed that air conditioning is used during six months of the year only.

Table VII-10: Average load flexibility potential per technology and company

Technology	Share of flexible energy of technology consumption $\boldsymbol{\varphi_j}$	Flexible potential in GWh of our subsample	Average flexible potential per company in MWh ($\Delta \boldsymbol{l}$)
Ventilation	4.1%	0.326	1.92
Air conditioning	10.7%	0.866	5.25

To then estimate the flexible annual volume and the subsidy cost per unit of volume as a function of the subsidy level, we use the probability distributions estimated for the individual technologies in Table VII-6. We assume that all companies in the choice experiment subsample use these technologies so that the companies who were asked about them can be taken to be representative of all companies in the subsample. Results are shown in Figure VII-4 and Figure VII-5.

Figure VII-4: Estimated flexible volume as a function of the subsidy (in €)

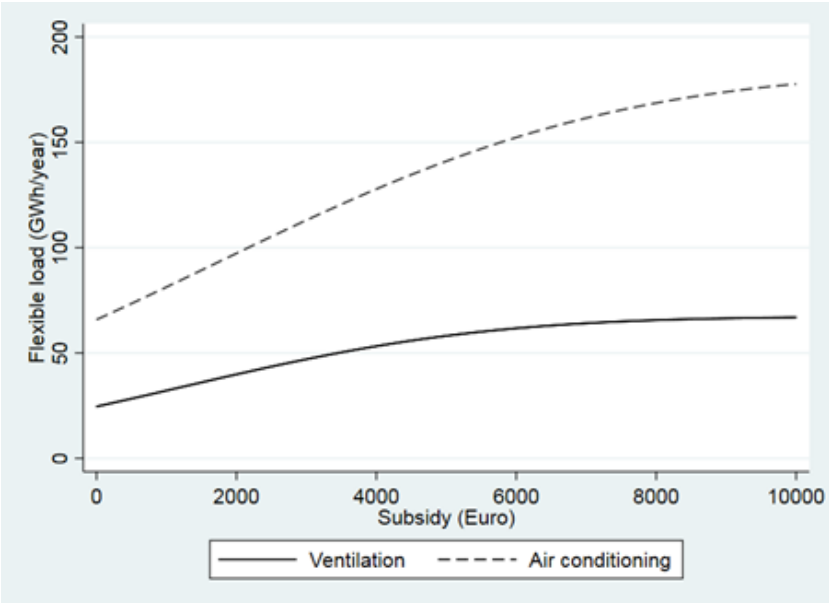
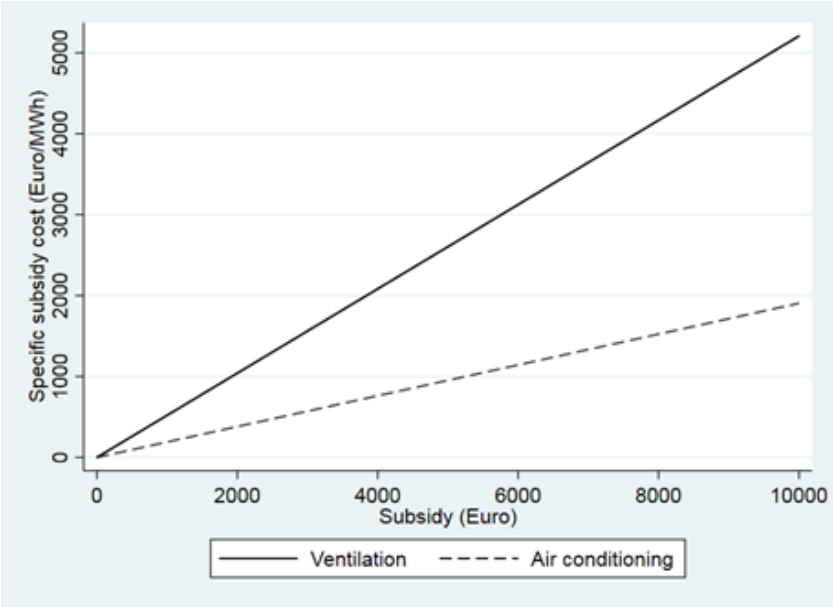


Figure VII-5: Estimated specific subsidy cost as a function of the subsidy (in €)



The simulation results suggest that for both technologies higher subsidies can give access to more potential but at decreasing marginal rates and thus increasing specific cost. Air conditioning appears to offer more volume at lower cost than ventilation. We consider our estimates most reliable for subsidies values nearer to the center of the probability distributions estimated in Table VII-6. At a subsidy of €1500 per company per year, a volume of 36.1 GWh can be mobilized in ventilation for €28.2 million total subsidy expenditure and €781 per MWh specific cost. In air conditioning, the same subsidy is expected to unlock a potential volume of 89.3 GWh for €25.5 million total and €286 per MWh specific cost.

The specific costs at this level of subsidy can be compared to alternative options for delivering balancing services. At the German balancing market, payments amount to €644 per MWh activated. For batteries, Newbery (2018) reports estimates for levelized costs between GB£76 per MWh (Tesla in 2020) and GB£586 per MWh (lead-acid). For pumped storage, Newberry (*ibid.*) estimates levelized costs between GB£43 and GB£91 per MWh for six existing plants in the UK. Hence, our estimates suggest that load management in the commerce and services sector could potentially be valorized on the balancing market and offer a competitive alternative to storage technologies.

4 Discussion and conclusions

In this contingent valuation study, we estimated companies' willingness to accept (WTA) automated, externally controlled load management on their electricity using systems in exchange for an annual subsidy payment. We applied a double-bounded dichotomous choice (DBDC) experimental design to a sample of 1587 companies from the German commerce and services sector. We used a standard interval data model to find respondents' mean and median threshold subsidy level for each of four systems (ventilation, air conditioning, refrigeration, and freezing) and to test how the threshold subsidy relates to attributes of the load management measure and characteristics of the firm.

4.1 Findings

We find that mean and median subsidy levels vary by technology.[6] For ventilation and air conditioning we find expected mean reservations subsidies of approximately €1200 and €1700, respectively. The respective standard deviations of ~€3500 and ~€4500 may seem large but are not uncommon for DBDC contingent valuation studies (e.g., Cameron and Quiggin 1994; Alberini and Bigano 2015; Olsthoorn et al. 2017). For refrigeration and freezing, we find expected mean subsidies of ~€250 and ~€3000, respectively. The respective standard deviations of ~€10,000 and ~€8500 are even larger, which may be due to the bar-bell shaped response pattern in combination with the wider range of bids and lower degrees of freedom.

We find that companies' WTA increases if load can be curtailed at agreed time slots only, but only for HVAC systems. For cooling systems, we find no evidence that such a restriction is valued. This may be due to cooling being a continuous function, whereas demand on HVAC system services varies according to occupancy and the quality of service may be more sensitive to load variations. For neither HVAC nor cooling systems we find evidence that companies value the frequency and duration of the load curtailments under the load management scheme. We find no evidence that experience with load management (on unspecified systems) increases WTA.Our results seem to suggest a negative effect when HVAC is concerned, which may be because the low-cost potential is already used and unavailable.

Using estimated distributions of the reservation subsidy for ventilation and air conditioning, we estimated that air conditioning promises more and more cost-effective potential. Subsidy levels in the center of the distribution yield specific subsidy costs per available MWh that suggest that load management in the commerce and services sector may become a competitive option on the balancing market.

6 Please, note that mean and median refer to the mean and median of the companies that took the choice experiment, i.e. companies that were identified as potential adopters based on their stated willingness to consider implementation of automated load management and had 10 or more employees.

4.2 Limitations

Our study is not without limitations. The following needs to be considered when taking in the findings. Our approach assumes that our respondents participate on behalf of their companies as economic agents with well-developed preferences that respond to incentives. However, for three of the four flexibility technologies considered we did not find that acceptance rates were higher for higher subsidy levels. Furthermore, the response pattern appeared rather polarized, with many yes-yes and no-no responses and few in between (yes-no and no-yes). With such a pattern, the double bounded dichotomous choice experiment may not have contributed to lowering the standard errors compared to a single bounded dichotomous choice experiment (Cameron and Quiggin 1994). Moreover, automated load management may be a new phenomenon to many companies in the commerce and services sector, most of which are SMEs, even in general. They probably lack "market experience" with load management and do not have well-developed preferences, which are two conditions for robust findings using a standard interval model that assumes constant preferences (Carson and Hanemann, 2005, p. 875-6). We are less concerned with hypothetical bias, because this has been shown to be generally minor compared to other biases such as strategic bias. When observing the commissioner of the survey and the resources allocated to it, a respondent is unlikely to believe that the outcome is inconsequential and may thus respond strategically in the interest of his/her firm (regardless whether questions are framed as hypothetical) (Carson and Hanemann, 2005, p.877). Strategic behavior may have contributed to the high shares of yes-yes and, especially, no-no answers for all technologies.

4.3 Implications

We have shown that a subsidy may incite a significant share of companies in the commerce and services sector to accept automated load management. At the same time, the large shares of yes-yes and no-no responses for all technologies, the large spreads of estimated reservation subsidies, and the discussed limitations, raises the question: can the cost-effectiveness of a subsidy scheme be improved and its uncertainty reduced, if it is preceded or accompanied by policy instruments (e.g. informational, experimental) that help companies form their preferences? We encourage further research that can contribute to the efficient unlocking and use of load management in companies.

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Chapter VIII

Energy Efficiency and Demand Response – two sides of the same coin?

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Abstract

To accommodate the increasing share of intermittent renewable energy, options need to be evaluated to maintain a profitable, secure and sustainable energy supply. Besides energy efficiency (EE) as "first fuel", adapting demand to meet the variable supply needs to be evaluated. We focus on concepts of energy efficiency and load flexibility (further: demand response; DR) and compare the two types of measures with respect to the diffusion of actions taken and possible drivers and barriers affecting uptake, we derive recommendations to promote the measures more effectively and synergistically. We analyse the results of a survey of more than 1500 service sector companies in Germany and supplement the results with research on German policies promoting energy efficiency and how these could also promote DR. We use logistic regression models to assess and compare influencing factors. Energy efficiency measures are much more prevalent than demand response measures, while most of the influencing factors for both are comparable. More information and standardisation will be needed to tap the demand response potential. We assume that the successful instruments and policies for energy efficiency could also be applied to foster demand response. Especially, instruments such as Energy Efficiency Networks could be redesigned to include demand response. The same holds for other established, effective regulatory instruments like energy audits, which could be enhanced by adding demand response. Although energy efficiency and demand response measures might counteract in specific cases, promoting DR measures can to a large extent built synergistically on existing energy efficiency policy.

1 Introduction

The transformation of the present unsustainable energy system towards a sustainable one is facing new challenges to ensure an affordable and secure energy supply. New strategies and measures are needed that might affect energy consumers. Especially the improvement of energy efficiency and renewable supply are seen as key in the transformation process (European Commission, 2018). To integrate variable renewable energy sources, a flexible consumption (i.e. demand following supply) could - next to energy savings - play an important role. The Energy Union refers to this as the "Energy Efficiency First Paradigm", explicitly including both energy savings and demand response (European Climate Foundation, 2016).

Energy efficiency (EE) improvement is defined as increasing the output per unit of energy used, resulting in energy savings if the output does not change. Changing consumption patterns to optimise the usage of energy supply is usually referred to as demand response (DR). It aims to improve the utilization of power plants and grids, and is seen as a way to more efficiently use the power system. In that sense, DR is an important instrument to also improve energy efficiency (EED, EC, 2012), underlining that energy efficiency and DR are not isolated and should be considered in parallel (Ecofys, 2016). Thus, synergies between EE and DR are standing to reason, being two aspects of the same goal in the energy transition, but also counteracting effects exist. The less energy is needed by the consumers, the fewer power plants are necessary; but with increasing shares of (intermittent or variable) renewable energy sources like wind and solar, the need of demand flexibility grows. The value of flexibility and efficiency depends on the availability of energy, and therefore changes during the course of the day and year. The considered entity of the energy system and its boundaries can change the evaluation of energy efficiency (Schlomann et al., 2015). A single energy consuming process (e.g. a production process or an appliance) might be operated less efficiently if it is used to support flexible demand (Boßmann et al., 2015), while flexible demand can help to operate the regional or national energy system more efficiently. Ecofys (2016) shows how energy efficiency and flexibility measures can interact on the level of industrial processes. These interactions are of special relevance for appliances of interest for both kinds of measures (e.g. heating and cooling appliances).

In this study, we focus on German companies in the service sector, including both energy efficiency and demand response. We found this sector to be an interesting target group, representing a significant share of electricity (and peak) demand (AGEB, 2018; Klobasa, 2007). Some studies estimate the maximum (shiftable) load even higher than in the industrial sector, but the loads and the consumption are also distributed on more companies. This increases the effort to tap their potentials, but due to the geographically distribution, companies from the service sector can contribute to demand side management also on lower grid levels. The potentials of the service sector are not fully exploited yet, especially regarding DR. To accelerate the diffusion of measures, finding synergies and making use of experiences with EE is of special interest.

A more active role is expected from energy consumers, i.e. companies in the energy transition, like changing energy consumption towards higher efficiency, providing flexibility or taking their role as "prosumers" (i.e. as consumers and producers of energy and as flexibility providers, European Commission, 2019). Usually, barriers towards EE and DR can counteract the advantages and need to be considered in designing policy strategies:

- Energy efficiency is a well-known concept, as energy savings are directly linked to cost savings. Typical, cross-cutting energy efficiency measures are thoroughly assessed (Fleiter et al., 2012, Wohlfarth et al., 2018a) and also much research has been carried out to learn about the reasons why possible measures are not taken (e.g. Jaffe and Stavins, 1994). Well-developed approaches on energy efficiency barriers exist, distinguishing economic, behavioural and organisational barriers, distinguishing imperfect information, risk, hidden costs, access to capital, split incentives, bounded rationality (e.g. Sorrell et al., 2004 and 2011, Cagno et al., 2013, Trianni et al., 2013). Fleiter et al. (2012) give an overview of the most important barriers for energy efficiency measures in SMEs (small and medium-sized companies), which are often associated with lack of time, money and priority. Schleich and Gruber (2008) applied the taxonomy from Sorrell et al. (2004) on the service sector and found the barrier of missing information most prevalent, while the importance of the barriers varied between the subsectors. Their analyses showed that more than 45% of companies in the service sector were active in energy efficiency. According to a modelling approach for the efficiency gains in Germany's tertiary sector, about 16% reduction in final energy demand in 2030 compared to 2008 can be expected if "near economic" potentials are tapped (26% on EU level, DG ENER, 2014).
- DR is seen as an important enabler of the integration of renewable energies, security of supply and consumer empowerment in Europe. In Germany, especially potentials of the energy-intensive industrial sectors are tapped so far, but potentials in other sectors also exist (Weißbach, 2015; Klobasa, 2007). Their participation could be increased if automated control technology is cheap and available, but still, the regulatory framework needs development and clarity of market roles. For smaller flexible loads as they can be provided by the service sector, prequalification criteria to participate in the balancing markets are hardly met and pooling of loads is rarely beneficial for aggregators or DR-service providers (Eßer et al., 2016). A restricted market-access and the low economic potential of DR for companies of the service sector prevent participation in DR. Additionally, other regulations promoting a predictable electricity consumption exist (e.g. the StromNEV 2005) and represent a barrier for the use of DR or a flexible demand, respectively. In the case of Germany, the value of DR is highly dependent of the penetration of renewable energies in the energy system and on system reliability. Thus, for the provider of flexible loads, the value of flexibility is more dependent on external conditions like market offers and regulations, weather conditions and the point of time of availability of flexibility in contrast to energy efficiency measures that might pay off just by reducing energy costs compared to being energy inefficient. This implies that different barriers might

affect DR more than EE measures. The service sector has not been very active so far in DR (Weißbach, 2015; Wohlfarth et al., 2018b), although a considerable potential can be expected (up to10 GW peak power and 6 TWh flexible demand, Klobasa, 2007, cp. Wohlfarth et al., tbp. for an overview). In a qualitative stakeholder analysis on DR in the service sector barriers towards DR have been identified: Especially the regulatory framework, lack of awareness, lack of clear corporate policies, financial issues and worries about quality loss of work or products were mentioned (Wohlfarth et al., 2018b). A study on DR in the non-domestic sector (Element Energy Limited, 2012) identified "cultural/ institutional" barriers as the most frequently cited barriers. Although this previous research indicates comparable categories of barriers towards DR as for EE, there is no comparable and structured taxonomy of barriers for DR so far.

This raises the question how to kick-start companies to engage in DR and whether synergies between EE and DR can be used to enhance penetration. We use data from a survey comprising over 1500 companies of the service sector to investigate the following research questions:

- To which degree have EE and DR measures been implemented in the service sector?
- Which aspects or characteristics promote EE respectively DR measures? Which barriers exist, and are these comparable for EE and DR?
- How can the existing knowledge and experiences from EE be used to promote DR?
- Can policy instruments be developed synergistically to promote both EE and DR?

2 Data and Methods

Mid-2017, we conducted a standardised survey via telephone interviews of more than 1500 German companies from selected subsectors in the service sector. The person in charge of energy issues of each participating company was interviewed on energy efficiency and demand response/load management with the help of a market research institute (GfK Germany). The survey focused on the subsectors with the largest share of electricity consumption within the service sector, i.e. offices, trade, and hotels/restaurants. Details on the relevant items of the questionnaire can be found in the appendix. Together these are responsible for about 60% of the electricity consumption of the sector (Schlomann et al., 2015). The total maximum load of the service sector can be estimated to 10 GW (Klobasa, 2007).

We used quotas concerning size and subsector to generate our sample. Nevertheless, the sample is not representative, meaning that the share of small companies does not outnumber the larger companies, which allows for statistical analyses within the categories of size and sector (Table VIII-1). Results concerning the total sample were weighted to

represent the overall population, using a weighting procedure developed by GfK Germany based on the linear weighting approach of Cassel et al. (1976) and the total number of companies (Destatis, 2015).

Table VIII-1: Structure of our sample

Subsectors and numbers of companies ⇩	**Size ⇨**	**small (1-9)**	**medium (10-49)**	**large (50 and more)**	**total**
Offices	offices	147	266	262	675
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
Hospitality	hotel with restaurant	30	75	22	127
	hotel	31	12	2	45
	restaurant	68	93	23	184
Total		456	691	437	1584

We use statistical methods to evaluate relations between DR and EE in the companies and influencing factors like company characteristics, barriers and conditions (e.g. available technologies or earlier experiences with energy issues). Next to weighted calculation of frequencies, we use logistic regression analyses to measure the strength of influences of the factors. Logistic regression is the statistical technique used to predict the relationship between predictors (our drivers/ barriers, resp. influencing factors) and a predicted variable (if measures have been conducted or are planned within the next 3 years) where the predicted variable is binary. The equation is described as Equation 1:

$$\ln\left(\frac{P\ (Y=1)}{P\ (Y=0)}\right) = a + \sum_1^i \beta_i * x_i \qquad \text{Equation 1}$$

P = Probability that the dependent variable Y equals a case (0 or 1)
x_i = predictor variables
i = number of predictors
β = weighted factors belonging to the predictor variables
a = constant

On the basis of the literature, we identified a set of company characteristics expected to affect implementation of EE or DR measures and evaluated the importance (Wohlfarth et al. 2018a, 2018b, Trianni and Cagno, 2012, DeCanio, 1998). We differentiate organisational factors that apply or do not apply (i.e. yes/ no categories) to a company (having e.g. conducted an audit) and drivers/barriers that apply to some degree (e.g. the expected organisational effort for implementation). We chose the following company characteristics:

- size of the company (i.e. dichotomized to less or more than 50 employees)
- affiliation to sector (dummy-coded variables, i.e. each in contrast to the affiliation to offices)
- audit carried out in the past (yes/ no)
- availability of BMS (building management system) or EnMS (energy management system, e.g. ISO 50001) (yes/ no)
- if investments are driven by profitability calculations (yes/ no)
- ownership of building (yes/ no)

Previous findings on barriers towards DR (e.g. Element Energy Limited, 2012, Wohlfarth et al., 2018b) and the well-established set of barriers to EE measures based on previous work of e.g. Sorrell et al. (2004; 2011), Cagno et al. (2013) and Trianni et al. (2013) indicate comparable categories of barriers for EE and DR on a more generalised level. Different types of economic, technical, behavioural and organisational barriers seem to be applicable on other kinds of energy-related measures in companies as well. In order to quantitatively compare the barriers towards EE and DR, we compiled a set of barriers suitable for EE and DR on that basis (see section 3.4). Considering DR and EE both as energy consumption related measures, we aim at finding out whether the structure of barriers is transferrable and whether the relevance and ranking of barriers differ. The participants were presented the two sets of barriers, so they had the chance to compare the aspects of EE and DR and recognise possible differences between the related barriers, if existent. The set of drivers and barriers can be categorized to describe the main factors. To distinguish drivers and barriers, drivers can be the counterpart to barriers, i.e. the absence of a barrier can be a driver for implementation. We selected a set of general statements (including drivers and barriers, rated on a 5-point Likert-scale) and composed a principal set of factors using factor analysis. A factor analysis is a statistical method used to describe correlated variables (i.e. drivers and barriers) in terms of a potentially lower number of underlying variables (factors) by combining groups of variables into meaningful factors that are as independent as possible from each other. Hence, a factor is a linear combination of variables that should be linear independent from the other factors. We have chosen this method because it is suitable for finding relationship structures in our data that can then be compared for EE and DR in terms of relevance and ranking.

3 Results

3.1 EE and DR measures in the service sector

Table VIII-2 shows that about 50% of the surveyed companies have conducted some kind of EE measures within the last five years. On average, larger companies conducted more measures than smaller companies. Hotels/ restaurants seem to be more active in EE than companies from the trade or office sector.

Regarding DR, a much smaller share of companies has conducted measures so far. Comparable to EE, the shares are highest in large companies and hotels/restaurants, but much lower in total. It should be noted that due to the large share of small companies in Germany (over 90% in our selected sectors (Destatis, 2015)), their answers dominate the total numbers. The share of large companies conducting DR measures is distinctly higher (see Table VIII-2).

Table VIII-2 below shows the share of companies that conduct measures (EE/DR). The category "EE/ DR 3 years" comprises companies stating to conduct measures now and companies that plan to conduct measures within the next three years. The shares rise in all categories for EE as well as DR, however, DR does not reach the level of EE measures already carried out.

Table VIII-2: Comparison of the occurrence of EE and DR measures in the service sector

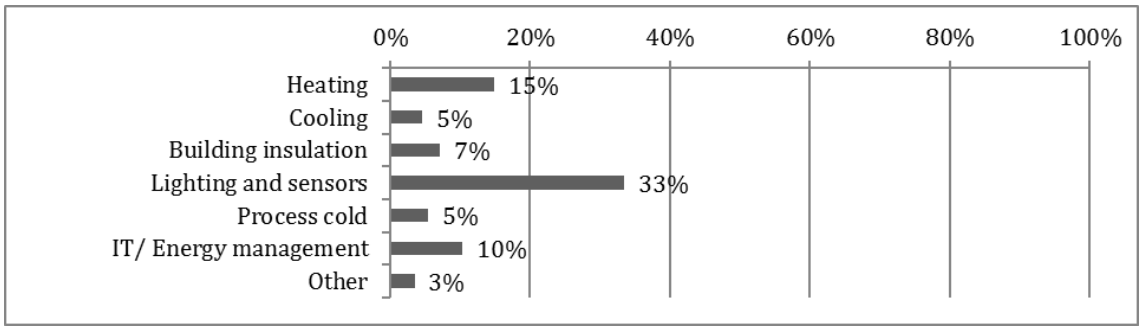
EE (total)	**category**		**DR (total)**	**category**	
48%	Small (1-9)	47%	4%	Small (1-9)	3%
	Medium (10-49)	60%		Medium (10-49)	6%
	Large (50+)	73%		Large (50+)	15%
	Offices	42 %		Offices	2%
	Trade	54%		Trade	4%
	Hospitality	65%		Hospitality	11%
EE 3 years (total)	category		**DR 3 years (total)**	category	
57%	Small (1-9)	56%	9%	Small (1-9)	8%
	Medium (10-49)	73%		Medium (10-49)	13%
	Large (50+)	84%		Large (50+)	25%
	Offices	49%		Offices	5%
	Trade	66%		Trade	9%
	Hospitality	76%		Hospitality	23%

The survey asked companies whether EE or DR measures are easier to implement. Most of the companies favoured EE (65%), confirming the results above. Interestingly, there is also a share of companies (especially those from the hospitality subsector) favouring DR measures (4%) or both kinds of measures equally (11%). About 20% of the surveyed companies stated that none of the measures were applicable.

Taking a closer look on EE (Figure VIII-1), most of the measures focus on lighting, followed by heating and IT/energy management. Multiple answers were possible, thus the shares do not sum up to 100%. We found differences between subsectors and sizes (Table VIII-9, in the appendix). Measures including climate control are more common in the hospitality sector (15%) compared to the other subsectors, and rarely done in small companies (<5%). Building insulation, too, is especially done in large companies (almost 20%) and in the hospitality sector (15%). Comparable results were found for process cooling, while IT/energy management measures are especially conducted in offices (12%).

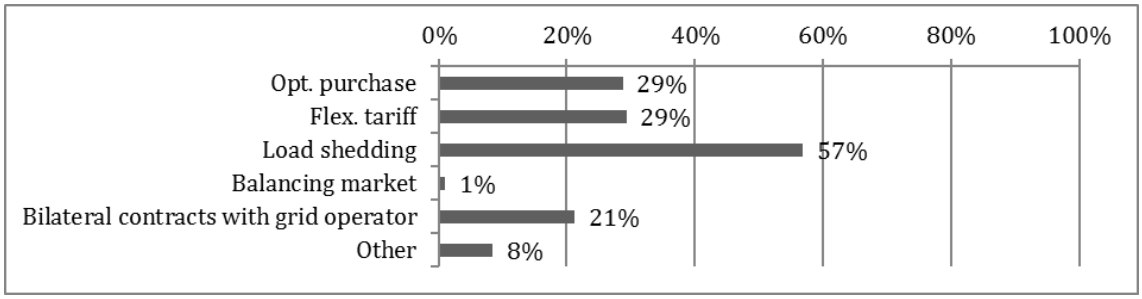
Already 17% of the companies that implemented EE measures stated that at least one of the measures was funded or financed by the German federal government or –state (Bundesländer) incentives. This applied especially to heating (11%) and insulation (16%) (multiple answers possible).

Figure VIII-1: Typical EE measures in companies of the service sector (n = 781, equals 48% of the surveyed companies)



Most of the companies conducting DR mentioned load shedding, followed by flexible tariffs or optimised purchasing of electricity (Figure VIII-2) as DR activities. The service sector has hardly entered the balancing markets. The shares differ between subsectors and sizes (Table VIII-10, in the appendix). Optimised purchasing of electricity (e.g. at the power exchange to match the consumption) is most common in companies of the trading sector (almost 50%), but hardly in the office sector (<5%). In offices, time variable tariffs and load shedding seem to be more common than in other subsectors. Participating in balancing markets is generally rare, i.e. none of the small companies stated to participate, while only 8% of the large companies did. One reason might be the minimum bids to participate that prevent small companies with smaller loads to enter the market. Bilateral contracts for load cut-offs are more common in small than in larger companies, but unusual in the trade sector (<1%).

Figure VIII-2: Typical DR measures in companies of the service sector (n = 55, equals 4 % of the surveyed companies)



3.2 Company characteristics influencing the implementation of EE and DR

Table VIII-3 shows the frequencies of the influencing factor (company characteristics) that are expected to affect implementation of EE or DR. Most are correlated with the size of the companies and specific subsectors. The distribution of the influencing factors amongst the companies differs. It can be assumed that EE or DR measures are more common where the influencing factors are in place.

Table VIII-3: Frequencies and distribution of influencing factors on EE/DR measures

Influencing factor	**total**	**Sizes**		**Sectors**	
Audit conducted	22%	Small (1-9)	21%	Offices	19%
		Medium (10-49)	34%	Trade	25%
		Large (50+)	60%	Hospitality	31%
Availability of BMS	8%	Small (1-9)	6%	Offices	7%
		Medium (10-49)	13%	Trade	8%
		Large (50+)	35%	Hospitality	9%
Availability of EnMS	3%	Small (1-9)	2%	Offices	3%
		Medium (10-49)	7%	Trade	2%
		Large (50+)	22%	Hospitality	4%
Investments driven by profitability calculation	43%	Small (1-9)	41%	Offices	39%
		Medium (10-49)	60%	Trade	48%
		Large (50+)	80%	Hospitality	45%
Ownership of building	41%	Small (1-9)	41%	Offices	37%
		Medium (10-49)	49%	Trade	42%
		Large (50+)	61%	Hospitality	61%

Using binary logit regression models, we investigate the influencing factors for planned or already implemented EE or DR (Table VIII-4). Each model (EE and DR measures) is significant with a large effect ("f" in Table VIII-4, cp. Cohen, 1988, 1992). For EE and DR, using a BMS, EnMS and using profitability calculations increases the probability to conduct DR and EE measures (at least 52% in case of DR and profitability calculations, the other variables like using a BMS or EnMS even more). Having conducted an audit as well as building ownership significantly increase the probability to conduct EE measures, but not DR measures. The affiliation to a certain sector (i.e. trade or hospitality - compared to offices) and the company size significantly increases the probability to conduct DR, but not EE. It seems that DR better fits certain types of companies (large ones, those from trade and especially hospitality sector) while EE does not seem to be that specific. The analysis also shows that the influence of management tools, i.e. building management or energy management systems as well as systematic profitability calculations are stronger for EE than for DR. However, the opposite applies for structural aspects (i.e. size, sector), where

only effects for DR are identified. Ownership of building and audits have no significant effect on DR, as audits usually only involve EE, and exclude DR, and because DR usually focuses on the appliances and the load profile, and not necessarily the building itself (often a focus of audits).

Table VIII-4: Comparison of influencing factors on conducting EE/DR measures

EE measures 3 years	**Regression Coefficient β**	**Odds Ratio Exp(β)**	DR measures 3 years	**Regression Coefficient β**	**Odds Ratio Exp(β)**
Audit	1.332***	3.787	**Audit**	.261	1.298
BMS	1.088**	2.968	**BMS**	.807***	2.241
EnMS	1.243*	3.466	**EnMS**	.525*	1.691
Profitability calc.	.962***	2.616	**Profitability calc.**	.483*	1.621
Ownership of building	.623**	1.865	**Ownership of building**	.351	1.420
Trade	.253	1.288	**Trade**	0.998***	2.714
Hospitality	.310	1.363	**Hospitality**	1.559***	4.755
Large enterprises	.207	1.229	**Large enterprises**	.651**	1.918
(Constant)	-.245	.782	**(Constant)**	-3.302***	.037
PAC	80.7		**PAC**	79.3	
Nagelkerke's R^2	.255 (f=0.59)		**Nagelkerke's R^2**	.175 (f=0.46)	
Chi^2	156.149***, df = 8, n = 906		**Chi^2**	110.723***, df = 8, n = 917	

Levels of significance: * = p ≤ .05, ** = p ≤.01, *** = p ≤ = p ≤.001

PAC: percentage accuracy in classification, indication for the quality of the regression model

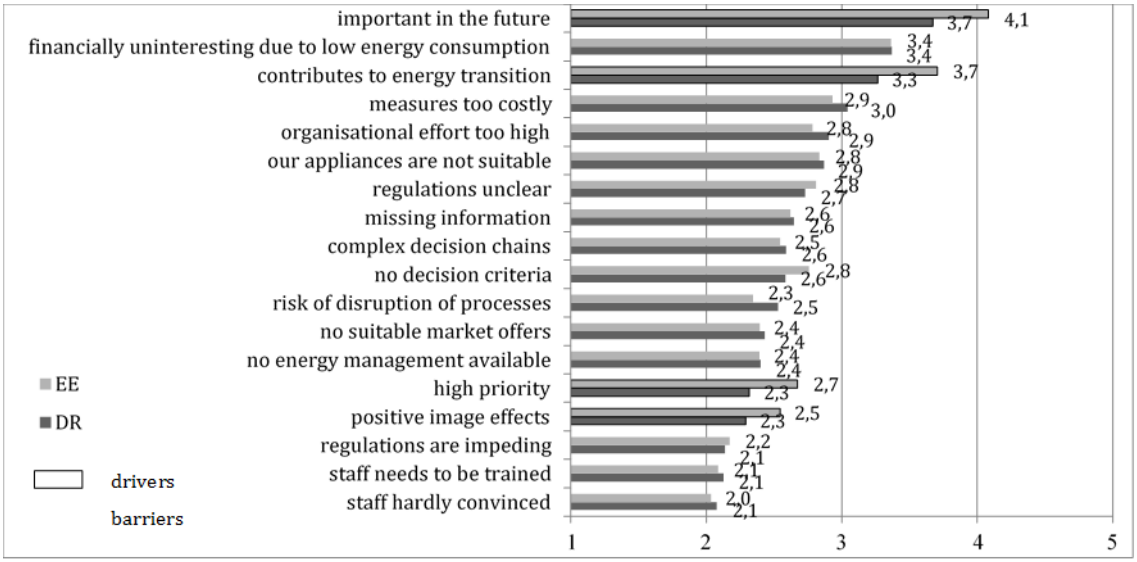
We asked the companies about the role of audits for EE. As a weighted share, 22% of the surveyed companies have conducted an audit (Table VIII-3). The shares are higher in large companies and hotels/restaurants. Only of the companies that did an audit and implemented EE measures, 46% stated that the measures were implemented as a consequence of the audit. This confirms the effect of audits in the regression analysis above, demonstrating that audits have a large influence on implementing EE.

3.3 Barriers and drivers towards DR and EE

Based on the findings of drivers and barriers to EE, we introduced a set of statements representing drivers or barriers (Figure VIII-3) – for EE measures as well as DR measures – to the survey participants. A ranking of the statements shows that the four highest ranked statements are the same for EE and DR measures (Figure VIII-3). The ranking was made on a 5-point scale, where 1 is the lowest and 5 is the highest level of approval. Financial aspects

are among the highest ranked barriers, followed by organisational and technical restrictions (suitability of appliances). The highest ranked drivers are general attitudes and convictions like the contribution to the energy transition and importance for the future. The largest differences between EE and DR occur for the drivers (i.e. future importance of the measures, the contribution to energy transition, priority and public image effects) where EE measures are rated higher. Regarding the barrier of the risk of disruptions of processes, DR is ranked higher.

Figure VIII-3: Comparison of barriers towards EE and DR – overall comparison for weighted means



We aim to compare EE and DR and to determine the main factors affecting EE as well as DR (Table VIII-5). We conducted a factor analysis to reveal the main categories for DR and EE, i.e. condensing the set of statements into a few factors. This analysis aims at describing variability among observed, correlated variables (statements) in terms of a potentially lower number of unobserved variables called factors. The results show comparable factors for EE and DR. The general attitude towards the measures converges in one factor, which has not been found in the EE barrier/driver taxonomies. For less well known measures like DR, the initial attitude might provide an impulse relevant for decision making and thus might be of higher importance. Another key factor is missing information or competences. Financial and organisational restrictions reduce the readiness for implementation. Motivational and regulatory aspects are ambivalent, including drivers like prioritisation of measures and the expectation of (positive) image effects. Regulatory restrictions were only by motivated companies considered as impeding factors. The factor of unsuitability describes the technical unsuitability perceived by the respondent (no appliances for measures available) and missing reasons/incentives for measures due to a low energy consumption. The variable of missing market options cannot be clearly assigned to a factor, as it is related to missing information, as well as unsuitability (esp. DR). The market does

not offer many options to participate in DR, and especially small enterprises are often disadvantaged, making DR unsuitable. In case of EE, the range of possible measures is larger and EE is better established. Thus, not finding a suitable measure might indicate missing information.

Table VIII-5: Factor analysis for EE and DR statements

factor loadings	**EE**	**DR**
positive conviction and attitude (mean)	3.90	3.47
contributes to energy transition	.812	.778
important in the future	.807	.855
unsuitability (mean)	3.11	3.12
financially uninteresting - low energy consumption	.767	.747
appliances are not suitable	.734	.665
~~no market offers~~	~~(.226)~~	~~.552~~
financial/organisational restrictions (mean)	2.65	2.70
complex decision chains	(.443)	.671
measures too costly	.684	.530
risk of disruption of processes	.708	.804
organisational effort too high	.625	.541
missing information/competence (mean)	2.46	2.43
no energy management	.762	.793
no decision criteria	.762	.752
regulations unclear	.747	.707
missing information	.619	.632
staff needs to be trained	.465	.546
staff hardly convinced	(.356)	.521
~~no market offers~~	~~.469~~	~~.408~~
motivational/ regulatory aspects (mean)	2.46	2.25
Existing regulations are impeding	.550	.573
high priority	.759	.732
positive image effects	.730	.672

EE: KMO (Kaiser-Meyer-Olkin-Criterion) = .813, Bartlett's test on sphericity: $Chi^2(153)=4981.35$***; DR: KMO = .805, Bartlett's test on sphericity: $Chi^2(153)=3362.50$***
Varimax rotation and Kaiser criterion used.
Unassigned variables: Market offers – for EE below .5 and cross-loading for DR on unsuitability as well as on missing information

Table VIII-5 shows that the main drivers and barriers are comparable for EE and DR. The two factor analyses for EE and DR converge to the same structure, i.e. the single aspects (drivers and barriers) show their highest loadings on the same factors. This finding supports the assumption that the set of barriers to EE are also valid for DR. Even the ranking of the factors is comparable. Nevertheless, highly rated drivers or barriers do not necessarily have the strongest influence on the decisions to implement measures. To

evaluate this influence and the differences regarding EE and DR, we conducted another regression analysis (Table VIII-6).

Table VIII-6: Influencing soft factors (drivers and barriers) on conducting EE/DR measures

EE measures 3 years	**Regression Coefficient β**	**Odds Ratio Exp(β)**	DR measures 3 years	**Regression Coefficient β**	**Odds Ratio Exp(β)**
positive conviction and attitude	.217**	1.242	**positive conviction and attitude**	.338***	1.402
missing information/ competence	-.292***	.746	**missing information/ competence**	.059	1.060
financial/ organisational restrictions	.103	1.108	**financial/ organisational restrictions**	-.092	.912
motivational/ regulatory aspects	.461***	1.585	**motivational/ regulatory aspects**	.633***	1.883
unsuitability	-.355***	.701	**unsuitability**	-.620***	.538
(Constant)	.439	1.552	**(Constant)**	-2.387***	.092
PAC	74.7		**PAC**	82.3	
Nagelkerke's R^2	0.134 (f=0.39)		**Nagelkerke's R^2**	.190 (f=0.48)	
Chi^2	144.142***, df=5, n =1493		**Chi^2**	175.852***, df=5, n =1406	

PAC: percentage accuracy in classification

Both regression analyses showed significant medium (EE) and strong (DR) effects ("f", cp. Cohen, 1988, 1992). A positive attitude increases the probability to conduct measures (24% vs. 40%), as well as motivational aspects (e.g. positive public image and a high priority at the management level). If measures are deemed inappropriate or the financial relevance of energy consumption is low, it negatively affects the implementation, reducing the probability by 30% (EE) resp. 46% (DR). Missing information and competence negatively influence EE. We did not find this relation for DR. We assume that information and offers are generally rare for DR and only those participants who have at least heard of DR were asked questions about statements on DR. This factor, therefore, does not discriminate the two groups of implementers and non-implementers. The coefficients show that all significant effects turn out to be stronger for DR than for EE. In both cases EE and DR, motivational/ regulatory aspects turned out to have the strongest influence compared to the other factors of drivers and barriers.

4 The policy landscape for EE and extensions to DR

To find out to which extent supporting policy instruments are already in place or how existing instruments could be enhanced or transferred to DR, we evaluate existing EE regulations and policies.
Different approaches to categorize policy instruments exist. Based on the categorization of UNFCCC (United Nations Framework Convention on Climate Change, 2000), we distinguish the categories:

- Financial (economic, fiscal)
- Voluntary/negotiated
- Regulatory instruments
- Information/education/training

Within these categories, different types of instruments exist. The policy instruments aim to incentivize specific actions and/or to remove barriers. Policies may include more than one of the categories, aiming to address several drivers or barriers. Table VIII-7 shows the general types and examples for policy instruments relevant for EE in companies.

Table VIII-7: Types and examples of policy instruments for energy efficiency

	Exemplary instrument types
Financial	Financial support schemes/ funds/ subsidies
	Loans
	Tariffs
	Taxes
Information	Subsidised consultation
	Information campaign
	Research and demonstration programs
	Education and training
Regulatory	Obliged information Labels
	Minimum standards
	Regulations/ directives/ acts/ ordinances
Negotiated/ voluntary	Agreed savings
	Agreed integration of certain technologies/ standards

We used the compilation of European energy efficiency policies of the MURE (Mesures d'Utilisation Rationnelle de l'Energie) database (Odyssee-Mure, 2018) to identify types of German instruments for energy efficiency that apply to companies. The instruments listed in Table VIII-8 start from 1995 and either apply or are generally applicable for the service sector (e.g. measures dedicated to industry that could be modified to match the service sector). Table VIII-8 shows the categorized energy efficiency policy instruments where we

also differentiated the general/ cross-cutting instruments and those for appliances or buildings specifically. Below we discuss how these instruments can be adapted to enhance the uptake of DR.

Table VIII-8: Compilation of German EE policy instruments

	General/ cross-cutting		Appliance/ Process	Building
Financial	KfW Energy Efficiency/Environmental Programme (Industry)			Upgrading the CO_2 Building Renovation Programme
	ERP Environmental Protection and Energy Efficiency Programme (funding)		Market Incentive Programme for Renewable Energies in Heat Market	
	Ecological Tax Reform (Energy and Electricity Tax)		Heat Power Cogeneration Act	Energy Efficiency Strategy for Buildings
	Funding for energy performance contracting		Upgrading KfW energy efficiency programmes for Industry	
	Promotion of energy management systems under the Energy Efficiency Fund		Stimulus programme for the promotion of climate protection measures in commercial cooling installations	
	Special fund for energy efficiency in SMEs	KfW Energy consultations for SMEs	BMWi Efficiency Fund: Promotion of energy-efficient cross-cutting technologies / promotion of energy-efficient and climate-friendly production processes	
Information	Eco-Management and Audit Scheme (EMAS)		Energy Efficiency Campaign	Information Campaign on Climate Protection (cp. EPBD)
	Energy Efficiency Networks Initiative			
Regulatory	Smart Metering	Energy audit obligation for non-SMEs	Top Runner Strategy	
			EU-related: Ecodesign Directive for Energy-using Products (Directive 2005/32/EC) & Ecodesign Directive for Energy-related Products (Directive 2009/125/EC)	EU-related: Energy Performance of Buildings, EPBD (Directive 2002/91/EC & Directive 2010/31/EU)
	Act on the Promotion of Renewable Energies in the Heat Sector - Heat Act			Thermal Insulation Ordinance
Negotiated/ voluntary	Voluntary agreement with German industry I & II		Voluntary Agreement on CHP	

KfW=Kreditanstalt für Wiederaufbau (reconstruction loan corporation). The world's largest national development bank and Germany's third-largest bank in terms of total assets.
ERP=European Recovery Programme
CHP= Combined heat and power
BMWi=Bundesministerium für Wirtschaft und Energie (Federal Ministry for Economic Affairs and Energy)

Based on the existing policies concerning EE, the following policy recommendations can be derived to promote EE and DR synergistically.

Financial instruments:

Different kinds of financial instruments can be distinguished:

- Financial instruments could be transferred to DR for general/appliance/building related instruments by also funding DR or DR-ready appliances, and increasing the "smart-indicator" of the building (cp. *EPBD (Energy Performance of Buildings Directive)*, regulatory measures), comparable to policies or programmes that financially support investments in energy efficiency (cp. *KfW Energy Efficiency/Environmental Programme (Industry), ERP Environmental Protection and Energy Efficiency Programme*). Some of the EE policy instruments already promote the integration of renewable energies, which is an aim of DR as well (e.g. *Market Incentive Programme for Renewable Energies in Heat Market*).
- Other general financial measures are taxes, supporting organizational preconditions for measures (e.g. energy management systems, contracting) and funds combining financial and information measures:
    - The ecological tax reform aims at promoting renewable energy, e.g. by reducing the need of energy and by taxing energy that does not come from renewable sources. However, DR does not necessarily result in energy savings. To also promote flexible demand, increased electricity demand in favour of DR measures should be untaxed/ excluded from the taxation.
    - Energy management systems are positively correlated with conducting DR. Energy management systems can help to understand and monitor energy consumption and can also be used to identify DR potentials. Thus, promoting energy management systems by funds (cp. *Promotion of energy management systems under the Energy Efficiency Fund*) will support DR.
    - *Funding for energy performance contracting* could also include installations of (building) management systems that also facilitate DR measures. The policy could be extended by explicitly including DR under the term "energy performance". Contracting could also include other service providers that enable companies to participate in DR (e.g. by aggregating loads or optimise purchasing electricity at the wholesale market).
    - Measures like the *special fund for energy efficiency (for SMEs)* or energy consultations (cp. *KfW Energy consultations for SMEs*) combine financial and information aspects. In case of DR, this seems highly recommended, as DR is less established and thus information on DR is less known. The concept is directly transferable to DR: An energy advice can inform on possible DR opportunities, the financial measure lies in supporting the necessary investments to implement DR.

- Appliance related financial measures specially support specific energy efficient appliances (i.e. heating/cooling, cp. *Market Incentive Programme for Renewable Energies in Heat Market* or *Stimulus programme for the promotion of climate protection measures in commercial cooling installations*) or cross-cutting technologies, i.e. technologies that can be found in several companies/ sectors like e.g. heating and cooling appliances (cp. *BMWi Efficiency Fund: Promotion of energy-efficient cross-cutting technologies).* The appliances with high electricity consumption could be of interest for EE as well as DR. Policy instruments could be extended to also fund DR-ready appliances (e.g. integrated control technology or the option to continue the core process of the appliance while the energy consumption is lowered). It should be noted, that if energy saving appliances consume less energy, it will affect the DR potential. Alternatively (comparable to the *Heat Power Cogeneration Act for CHP*), a technological change to appliances that are easier to use flexibly (e.g. heat pumps to be used for DR) is an option and the promotion could work accordingly through tariff setting (like time-of-use metering and billing).

Information instruments:

- General information instruments refer to delivering information that can be used to support the implementation of measures, i.e. audits, cooperative networking processes, or delivering and monitoring consumption data (metering data, management systems).
  - Energy management and audits (cp. *Eco-Management and Audit Scheme (EMAS)*) provide information and monitoring of energy consumption. Especially the audits could be extended with a stronger focus to DR.
  - Energy Efficiency Networks aim at delivering information and achieving saving goals over a three-year period, including cooperation and exchange of experiences in a group of companies in order to lower transaction cost (Wohlfarth et al., 2017). The concept could work well for DR Networks and the networking process could even end up in cooperating to aggregate loads with the network coordinator or a mandated company as an aggregator.
  - Instruments combining information with regulatory measures aim to systematically provide the necessary information to encourage implementation, i.e. *Smart Metering* of energy consumption and the *energy audit obligation (for non-SMEs)*. Both can be used to deliver useful information on DR options. These aspects could easily be integrated in existing EE policy instruments.
- Appliance related measures provide information on best available techniques, best practice examples and encourage the implementation of related measures (cp. *Top Runner Strategy, Energy Efficiency Campaign*). Comparable to EE, this principle could be effective in case of DR, because few practical examples or best practices for DR in the service sector exist so far, hence delivering guidance on the implementation process (available appliances, techniques and practice) is of great relevance.

- Building related information refers to energetic characteristics of the building. Regarding the building and its potential for DR as a whole (cp. the "smartness indicator", cp. *Information Campaign on Climate Protection*, see regulatory instrument *EPBD* below), this kind of information can also be used to assess the DR potential.

Regulatory instruments:

The regulatory framework is still underdeveloped for DR (Wohlfarth et al, 2018b; SEDC, 2017). Guidelines need to be developed how to make use of the potentials and to enter the markets. Regulations specific for EE are hardly directly transferrable to DR, but in some regulations DR aspects could be integrated.

- The existing general policy instruments for EE promote the use of renewable energy and are compatible with goals of DR (e.g. *Act on the Promotion of Renewable Energies in the Heat Sector)*. Besides changing the energy carrier to renewable sources, DR can also indirectly support the integration of renewable energy, e.g. by shifting consumption to times where renewable energy is available. An obliged share of renewable energy consumption could also be reached by shifting consumption. This could be achieved by an obligation or by (financially) rewarding the energy consumption shifted in favour of the use of renewable energies if a lower market price of using renewable energies alone is not enough to incentivise the favourable consumption behaviour.
- DR could be included in the Ecodesign standards (cp. *Ecodesign Directives*) for applicable appliances, e.g. as "DR ready" appliances, provided with an appropriate label.
- The *EPBD* focuses on lowering the total energy consumption of buildings and does not inherently support DR. The proposal to amend the EPBD directive from 2016 includes the promotion of a "smartness indicator". This indicator is meant to "to assess the technological readiness of the building to interact with their occupants and the grid and to manage themselves efficiently" (EC, 2016) and hence is linked to (even automated) DR purposes. This EPBD could be a starting point for more specific measures.
- Thermal insulation aims at saving energy by avoiding losses (cp. *Thermal Insulation Ordinance*). The focus is more on EE than on DR. Especially when the need for heating/ cooling is decreased, the potential for DR can decrease (Boßmann et al, 2015; Kupzog et al., 2007). However, using a well-insulated building as thermal storage can also have positive DR impacts.

Negotiated/ voluntary agreements:

- Voluntary agreements (e.g. *Voluntary agreement with German industry I & II, Voluntary Agreement on CHP*) refer to energy saving targets or to increasing the use of energy efficient technologies. Translating these approaches to DR, agreements on flexibility targets (e.g. utilize a share of the total consumption for DR) could be established or the use of flexible (esp. electrified) appliances or control technologies analogous to efficient technologies.

5 Discussion of policy implications

Combining the survey results and the existing policy instruments, implications for policies and promotion of sustainable measures can be deduced. DR is less common and fewer options exist compared to EE. Therefore, decision making starts from a different level, even though DR and EE face common barriers and drivers. Regulatory clarity and commitment to the relevance of DR thus should be a priority. Especially because regulatory and motivational aspects seem to have the strongest influence on the implementation of measures. Due to the lack of regulations that clarify and structure market access of flexibility potentials, as well as the barriers to mobilize small-scale potentials, DR does not reach a high priority for companies, and profitability decreases. Currently, a large share of the companies is completely unfamiliar with DR. Thus, informational instruments seem necessary, but not before more and easier regulations and options for market participation for non-industrial companies have been established. A promotion with information and pilot studies could be effective and convincing, especially as the general attitude towards DR turned out to play a strong influencing role. Profitability and suitability of measures are strong driving forces in decision making. Furthermore, DR is more dependent on size and subsector. Hence, DR is more related to the availability of specific (flexible) appliances and control technologies. Policymaking should first provide clear and incentivizing regulations, secondly, enhance the profitability of measures and make flexible appliances ready for DR-use, and finally create a positive attitude towards DR, e.g. by providing information on effects and options to participate, possibly supported by financial instruments or e.g. an incentivizing tariff structure for DR actions. While energy savings are inherently rewarded by saving energy costs, demand flexibility can be rewarded by time-of-use-tariffs that incentivize to shift loads. A relevant aspect in the harmonisation of the policies is the clarity of priorities, i.e. policies with different goals should not interfere or even contradict and if they do nevertheless, a corresponding compensation should be provided.

Further steps of policy instruments could be:

- A regulatory framework for the market integration, including for smaller loads by supporting contracting/aggregation of loads and establishing tariffs for DR. This would especially provide chances to small companies to participate in flexible trading
- Promoting the “smartness indicator” of buildings to incentivize assessing and improving the potentials.
- Labelling and standardizing can give clarity and facilitate to get informed (cp. Ecodesign and energy labelling).
- Awards or labels for companies participating in DR could make DR visible and result in public image effects and work as a driver, e.g. for their marketing.
- Financial incentives like funds can promote DR-ready appliances that enable companies to participate in DR. SMEs might especially profit from funding, because they usually have smaller financial options, compared to large enterprises.

- Taxes, regulations and funds already supporting the integration of renewable energy (e.g. ERP, EcoTax) could be extended to also include DR, because they aim at the same targets. A bonus for flexibility in case of energy storage is already partially integrated, but could be extended in favour of DR measures e.g. by untaxing loads used for DR from electricity taxes.
- As soon as profitable and standardized options for DR exist, information instruments come into play. Energy audits should be extended and enhanced to also cover DR and inform about profitable and suitable measures.
- In a comparable manner, EE-Networks could be adapted to include DR. They should work with the same principles of cooperative exchange among companies, supervised by experts and goal setting. Either the DR-Networks could be additional to EE or the DR aspects could be integrated. Additionally, funding of suggested measures could be a future part, especially because measures started within the supervised setting of the networking process are most likely to be successful (e.g. measures combining financial and information aspects). The pilot cases within the networks could also function as best practice examples to encourage following companies to deal with DR measures.
- Further promotion to identify and make use of flexibility potentials could be given by funding control technologies/ BMS in a comparable way as funding EnMS. They can be promoted by synergetic policies for EE and DR, because they support both EE and DR.

6 Conclusions and Outlook

A sustainable energy system needs to involve both EE and DR. The analysis of the survey data revealed comparable factors influencing the intention to implement EE or DR. Nevertheless, DR is much less known or common and the share of companies familiar with DR is low (4% in case of DR compared to 48% in case of EE), the different status indicates a different relevance of needs and barriers. Some of the subsectors have more experience with DR than others, while this was not observed for EE.

We found aspects with a positive influence on the implementation of DR or EE. Especially the availability of EnMS or BMS facilitate the implementation of energy-related measures. Motivational and regulatory aspects, as well as a general positive attitude towards the measures have a strong influence on the decision-making regarding EE and DR measures. The factor analysis on drivers and barriers showed comparable main aspects. This suggests that the general taxonomy of barriers is to some extent transferrable to analyse the barriers to DR. The level of the barriers however, differs between EE and DR, especially regarding attitude and regulatory aspects. In addition we found that the attitude towards DR measures has a significant impact. This is not yet part of the EE taxonomy, and adding this aspect to the existing taxonomies should be further explored.

The findings on influencing factors can be used to design policies promoting EE and DR measures. In contrast to EE, the regulatory framework to tap DR potentials is less developed and has impeding effects on the implementation of measures. For DR, more persuasion is needed, as DR is not yet as well established as EE and the gains for the energy system are rated lower by the companies than gains from EE measures. As more knowledge in companies about EE exists, EE can open the door for DR. The knowledge on energy consumption in the companies gained by conducting EE can turn out to be useful to evaluate DR opportunities. Comprehensive instruments like the learning energy efficiency networks could be redesigned to also cover DR aspects. Audits positively influence implementing EE, but have little effect on DR so far. Synergies can be realised by including DR aspects in audits. Audits can have a special relevance in promoting measures, i.e. in pointing out the potentials, because being unaware of suitable measures turned out to be a strong barrier in implementing both, EE and DR. In contrast to EE, the regulatory framework to tap DR potentials is less developed. The experience with successful EE instruments can be used to support the implementation of DR. Some instruments like the promotion of EnMS already positively influence EE and DR. Comprehensive instruments like the learning energy efficiency networks could be redesigned to also cover DR aspects. Audits positively influence implementing EE, but have little effect on DR so far. Synergies can be realised by including DR aspects in audits. In contrast to EE, the regulatory framework to tap DR potentials is less developed.

The factor analysis on drivers and barriers showed comparable main aspects. This suggests that the general taxonomy of barriers is to some extent transferrable to analyse the barriers to DR. In addition we found that the attitude towards DR measures has a significant impact. This is not yet part of the EE taxonomy, and adding this aspect to the existing taxonomies should be further explored.

Familiar EE instruments can be extended to also favour DR. As more knowledge in companies about EE exists, EE can open the door for DR. The knowledge on energy consumption in the companies gained by conducting EE can turn out to be useful to evaluate DR opportunities. For DR, more persuasion is needed, as DR is not yet as well established as EE and the gains for the energy system are rated lower by the companies than gains from EE measures.

We found that new regulations, in particular related to electricity markets, to tap the DR potentials are needed. Supporting mechanisms do not need to be newly invented. Synergies within existing instruments can be exploited and shared benefits can be realized. Especially on the level of the energy system, the integration of renewable energy has already been included in energy efficiency instruments, and hence matches DR opportunities.

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Appendix

Table VIII-9: EE measures by sector and size

Measure (EE)	**Sizes**		**Sectors**	
Heating	Small (1-9)	13,9%	Offices	11,5%
	Medium (10-49)	19,1%	Trade	14,1%
	Large (50+)	33,0%	Hospitality	29,1%
Cooling	Small (1-9)	3,9%	Offices	2,5%
	Medium (10-49)	10,1%	Trade	3,7%
	Large (50+)	17,6%	Hospitality	15,0%
Building insulation	Small (1-9)	6,5%	Offices	6,5%
	Medium (10-49)	9,5%	Trade	3,5%
	Large (50+)	18,9%	Hospitality	15,0%
Lighting and sensors	Small (1-9)	32,0%	Offices	24,9%
	Medium (10-49)	46,5%	Trade	43,0%
	Large (50+)	53,1%	Hospitality	50,4%
Process Cold	Small (1-9)	5,0%	Offices	3,7%
	Medium (10-49)	9,1%	Trade	3,0%
	Large (50+)	15,4%	Hospitality	18,4%
IT/Energy Management	Small (1-9)	9,6%	Offices	12,0%
	Medium (10-49)	12,5%	Trade	6,3%
	Large (50+)	26,1%	Hospitality	8,5%
Other	Small (1-9)	3,4%	Offices	3,5%
	Medium (10-49)	4,0%	Trade	3,7%
	Large (50+)	6,4%	Hospitality	2,8%

n = 781, equals 48% of the surveyed companies

Table VIII-10: DR measures by sector and size

Measure (DR)	**Sizes**		**Sectors**	
opt. purchase	Small (1-9)	28,8%	Offices	4,2%
	Medium (10-49)	25,7%	Trade	48,7%
	Large (50+)	33,4%	Hospitality	30,5%
flex. tariff	Small (1-9)	29,1%	Offices	44,5%
	Medium (10-49)	33,1%	Trade	28,1%
	Large (50+)	27,7%	Hospitality	19,6%
load shedding	Small (1-9)	56,7%	Offices	88,7%
	Medium (10-49)	57,7%	Trade	52,5%
	Large (50+)	59,1%	Hospitality	37,7%
balancing market	Small (1-9)	0,0%	Offices	1,1%
	Medium (10-49)	5,3%	Trade	1,4%
	Large (50+)	8,2%	Hospitality	0,7%
bilat. contracts	Small (1-9)	24,7%	Offices	38,9%
	Medium (10-49)	3,2%	Trade	0,5%
	Large (50+)	4,1%	Hospitality	25,4%
Other	Small (1-9)	7,4%	Offices	6,7%
	Medium (10-49)	17,7%	Trade	19,9%
	Large (50+)	8,6%	Hospitality	0,6%

n = 55, equals 4% of the surveyed companies

Excerpt of the relevant questions from the questionnaire

English translation

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 demand peaks avoided.

Do you use load management?

- Yes
- No
- No answer

In what way do you use load management?

- Optimised purchasing of electricity at electricity exchanges
- Adjustment of consumption to a time-variable tariff
- Reduction of consumption peaks
- Participation in the balancing market
- Bilateral agreements with network operators on load balancing
- Other
- not specified

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

- Yes
- No
- Don't know/ no answer

Which of the conducted measures were taken as a result of the energy audit?

- none
- heating
- cooling
- building envelope
- lighting or sensors
- cold supply
- IT/ Energy Management
- other
- no information

Are you planning (further) measures to improve energy efficiency in the next 3 years?

- no
- rather no
- maybe
- rather yes
- yes
- not specified

Are you planning to implement (further) load management measures in the next 3 years?

- no
- rather no
- maybe
- rather yes
- yes
- not specified

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. Secondly, please tell me how much these statements apply to load management.
Please answer on a scale from 1 to 5: 1: does not apply at all, 5 totally applies.

- In general, it makes an important contribution to the energy transition.
- This topic will become 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 involves the risk of a disruption of the operational processes.

- It is difficult to convince our employees.
- 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 need extensively training for that.
- 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.
- The market offers are not suitable for us.
- The organisational effort of implementation is too high.
- The topic has high priority for the management.

Do you conduct profitability calculations in the advance of investments in the energy sector?

- Yes
- No
- not specified

Is the building of your company...

- hired
- leased
- company-owned

Is your company certified in terms of energy or environmental management?

- Yes, according to ISO 50001
- Yes, according to ISO 14001
- Yes, other certification (e.g. EMAS, Energy Efficiency Network)
- No

Do you use a building control system, a building management or energy control system or other electronic control systems for your appliances?

- Yes
- No
- not specified

Chapter IX

Summary and Conclusions

1 Summary and conclusions

The EU's long-term energy strategy aims at a prosperous, modern, competitive and climate-neutral economy by 2050 with the purpose of being in line with the Paris Agreement objective to keep the global temperature increase below 2°C or even more strictly to 1.5°C. Energy efficiency and increasing the share of renewable energies are key elements of this vision.

Improving energy efficiency has been an issue for decades, but despite that, the potentials are far from being exhausted and Germany is missing its target regarding the reduction of consumption even for 2020. Germany has been performing well in integrating renewable energies so far, but the increasing share will lead to challenges managing the volatility of supply. Regulations to make use of the flexibility potentials to support the integration of renewable energies are still underdeveloped. Obviously, there still are knowledge gaps concerning the tapping of energy efficiency potentials and demand flexibility potentials, where the number of practical experiences involving companies currently is low.

To deal with these knowledge gaps, the investigation of options to contribute to the energy transition by means of improving energy efficiency and demand flexibility is the focus of this thesis. Companies in Germany are chosen as examples to illustrate the potentials, its determinants and challenges. Amongst companies in Germany, considerable potentials regarding energy efficiency and demand flexibility can be expected.

This thesis is dedicated to the central question:

How can energy efficiency and flexibility options be realised synergistically in companies?

In order to answer this research question, the following sub-questions are addressed in the thesis:

RQ 1 *How can energy efficiency measures successfully be implemented in companies and which determinants need to be considered?*

RQ 2 *Which companies are target groups for demand flexibility in the service sector and how big is their potential?*

RQ 3 *Which determinants influence that flexibility potential in companies of the service sector?*

RQ 4 *How can we make use of synergies between demand flexibility and energy efficiency?*

The basis to answer these research questions are seven independent publications that evaluate potentials, influencing factors and recommendations of and for the practical implementation of energy-related measures in companies.

Chapter II: Learning networks as an enabler for informed decisions to target energy efficiency potentials in companies
Deals with the question how informed decisions targeting energy efficiency potentials in companies can be enabled.

Chapter III: Tailoring energy efficiency measures to target groups – approaches regarding cross-sectional technologies and barriers in industry
Investigates how energy efficiency measures need tailoring to different types of companies.

Chapter IV: Setting course for demand response in the service sector
Describes the regulatory situation for DR in Germany and answers the question where the potentials are, seen from the stakeholders' perspectives regarding the service sector.

Chapter V: Demand Response in the service sector – theoretical, technical and practical potentials
Provides an estimation of the DR potential in companies of the service sector and shows which factors influence the potential.

Chapter VI: The flexibility deployment of the service sector – a demand response modelling approach with evidence from a market research study
Focuses on the possible contribution of the service sector's companies to load management and RES integration.

Chapter VII: How much load flexibility can a euro buy? Findings from a choice experiment with companies in the German commerce and service sector
Estimates the expected financial profit of companies for their flexibility of demand.

Chapter VIII: Energy efficiency and demand response – two sides of the same coin?
Discusses what we can learn from the adoption of energy efficiency measures to also support demand flexibility.

Table IX-1 shows the contents and focuses of the chapters.

Table IX-1: Overview of chapters, research questions, main themes, focus and methods

	Research question				Main themes			Sector		Measures		Approaches/ analyses
Chapter	*RQ 1*	*RQ 2*	*RQ 3*	*RQ 4*	Potentials	Determinants	Implementation	Industry	Services	Energy efficiency	Demand flexibility	Methods
II	x				x		x	x		x		pre-post evaluation
III	x					x	x	x		x		factor analysis, significance tests, regression analyses
IV		x	x		x	x			x		x	qualitative stakeholder analysis
V		x	x		x	x			x		x	math. approach, regression analyses
VI		x	x		x		x		x		x	modelling approach
VII			x		x	x			x		x	choice-experiment/ contingent valuation
VII	x		x	x		x	x		x	x	x	policy analysis, comp. factor analysis, regression

1.1 Summary of the results

This section presents and discusses the main results from the publications with regard to the research questions.

Chapter II: Learning networks as an enabler for informed decisions to target energy efficiency potentials in companies

Chapter II analyses the monitoring data from over 350 companies from the manufacturing sector, participating in the "Learning Energy Efficiency Networks" (LEEN). LEEN combine aspects of information (like audits), shared experiences and moderated learning processes and allow the evaluation of expectations and barriers companies face, and of how information, cooperation and experiences can influence the success of implementation. The companies are supported through all steps of improving energy efficiency, beginning with an analysis of the situation and suggestions of profitable measures. A focus of the analyses lies on the expectations and needs of the companies and how they can be met.

The companies' main concern lies in practical knowledge and specific information, i.e. an analysis of the energetic situation, options to reduce energy costs and information concerning specific measures and technologies, which can be seen as expanded contents of an audit. The expectation ranked second referred to decision support and reduction of transaction costs by sharing experiences, going beyond what typical energy audits provide. Comparing the expectations with the fulfilment, they could well be met. Participation in the networks reduced the barriers of missing energy management and missing information or market overview. Economic issues of the measures could not be improved. Despite some ratings of barriers not improving, almost all companies (96%) implemented the suggested energy efficiency measures and 75% stated that these measures would not have been implemented without the networks. The quantitative monitoring performed by the energy manager and the consulting engineer resulted in an annual average efficiency improvement of 2.1% (compared to the average efficiency progress in industry of approx. 1%). Besides the quantification of results, the companies also profited from the networks by establishing contacts with other companies and gained the opportunity to cooperate in energy issues or for other purposes.
An additional value compared to other informative consultations like audits is seen in the supervision over 3 to 4 years, because different barriers can occur at different times in the process. Beyond a mere consultation or information, the networks thus function as enablers and provide the companies with the necessary support and practical knowledge. It can be assumed that the matching of the programme to the participants' needs is a key success factor regarding the concept of the networks. Against this background, it must be taken into account, that barriers are not solely related to measures, they also originate in a company's routines, processes and other characteristics. To fully exploit the companies' energy efficiency potentials, the measures need to be tailored to their characteristics and constraints.

Chapter III: Tailoring energy efficiency measures to target groups – approaches regarding cross-sectional technologies and barriers in industry

Chapter III takes a closer look at cross-cutting energy efficiency measures and barriers and how they relate to different types of companies to identify target groups. Therefore, the main barriers and their relevance for different company types are identified. This opens up the possibility of better matching of energy efficiency measures or services and companies and increases the probability that measures are actually implemented.

The analyses reveal that barriers related to the availability of time and money are ranked highest, reflecting the lower priority of energy issues compared to core business issues. A categorisation of barriers resulted in the main categories "financial/ economic restrictions", "constraints in technical/ structural circumstances", "motivational/ internal relevance" and "information or external market-related deficits". These categories are comparable to taxonomies of barriers suggested in the literature. The highest-ranked category of economic barriers relates to financial possibilities or the profitability of the measure which depends on the companies' assessment of profitability and this assessment is often made with unsuitable risk indicators of short payback periods. This barrier is especially present in companies that base decisions predominantly on financial aspects or which are part of a corporation and thus cannot independently decide about investments. The category ranked second highest (technical/ structural circumstances) can be influenced with consultation, energy management tools or –services. Motivational barriers are especially relevant in larger companies, companies with low energy costs or without energy-intensive processes. Especially the latter characteristics relate to small energy efficiency potentials and might thus demotivate measures. If regulations or directives distinguish company types, they usually base their distinction on the companies' size. Our analyses revealed that characteristics related to specific barriers are stronger and more frequent for SME (small and medium-sized enterprises, <250 employees) than for LE (large enterprises), indicating a larger heterogeneity within SME. The number of implemented energy efficiency measures is higher in large companies, most likely due to a larger production site and thus more facilities and technologies available. Nevertheless, different types of companies face different barriers and are more likely to implement different kinds of measures.

The suggested energy efficiency measures need to be related to the company's characteristics, not only to technical opportunities. Usually, many measures are technically appropriate while only a few are selected for implementation. Size and sector turned out to be relevant factors, but also the autonomy of the enterprise, relatedness to customers, how decisions are made, and the energy intensity play a role in finding appropriate measures for the company. To increase implementation, barriers need to be overcome. Shortages in time and money seem to be the first pitfalls where optional measures fail. Especially if energy is not a strategic issue, incentives for large efforts are low. A more foresighted assessment of profitability of measures and

attractive financing options could challenge these issues. One-stop solutions such as an energy service could keep the organisational effort and time used low. Usually, decision-making can be faster if it is made within the company (instead of e.g. by parent companies). A self-assessment tool for companies where appropriate energy-related measures can be screened based on the influencing factors mentioned might also minimise the effort and time needed to identify appropriate measures.

Chapter IV: Setting course for demand response in the service sector

A more flexible demand of electricity can help to challenge the integration of volatile renewable energy. Compared to the industrial sectors, the service sector has been explored less. Compared to industrial sectors with higher energy consumption and flexibility potential per company, trading flexibility is more difficult for less energy-intensive companies of the service sector. In Germany, flexible loads can be traded on the balancing and the spot market. Congestion management can be used under the "sheddable loads act". The flexible consumer loads have to prequalify (i.e. meet technical requirements) in order to participate. Recently, the minimum bids have been adapted to also allow participation of smaller loads (between 1 MW and 5 MW) and the loads can be pooled, e.g. by third-parties like aggregators. However, the standardised processes for contracts between aggregators, balancing managers and suppliers are not yet clearly defined and form a regulatory barrier. Additionally, the "Electricity Network Charge Ordinance" (StromNEV) constitutes another regulatory barrier for the use of DR potential, counteracting demand flexibility by incentivising a consistent, predictable demand. Thus, particularly large, energy-intense companies (i.e. industry) or third-party players (e.g. virtual power plants) have entered the aforementioned markets. Many smaller consumer loads still do not fulfil the prequalification criteria. Pooling is an option but is currently rarely beneficial. Some larger enterprises from the service sector use their flexible demand to minimise peak loads, use flexible tariffs or try to optimise the purchasing of electricity. Therefore, it can be assumed that the DR potential of the service sector is mostly unused but could be valuable for grid management or to support the integration of volatile renewable energies.

The subsectors trade, restaurants, hotels and offices turn out to be the most promising subsectors. Combined they account for more than 50% of the total electricity consumption of the tertiary sector. A substantial share of this electricity consumption in these subsectors is caused by appliances that can be operated flexibly. These flexible cross-cutting appliances are cooling, heating, air-conditioning (AC) and ventilation, and electric warm water heating. Stakeholder interviews are taken into account to learn more about how to make use of the flexible demand in the selected target sectors. In offices, DR is a non-issue so far, but potentials are found especially in AC and ventilation. In large, modern buildings, control technologies are already available and could facilitate the use of the flexible demands. The interviewees pointed out that the measures should not interfere with the needs of the employees, fearing that the quality

of work could suffer. In this case, the behaviour of the staff might interfere with the measures, e.g. if the AC is used for DR and people open the windows. The trade sector also has potential in ventilation and air-conditioning (VAC) and in the food sector cooling and freezing appliances can be used for DR. Depending on the stores, specific appliances like baking machines or entertainment devices can increase the potential. These potentials have partially been recognised and options to make use of them are taken into consideration. Aggregation of potentials might be easier in the retail sector, e.g. if several stores belong to the same company. Decision-making might also be easier if only the headquarters need to be convinced and the measures are rolled out in the stores. The regular phases of refurbishments can be used to install the necessary control systems. In the hospitality sector (hotels/ restaurants), besides VAC and cooling devices, kitchen appliances cause high loads and can be used for DR. In large kitchens, these control technologies often already exist for load shedding purposes, but the kitchen devices usually lack flexibility and need to be ready on demand when meals for guests have to be prepared. All stakeholders agree to the general relevance of DR options, but have reservations concerning costs or the possible interference with working processes. That issue is seen especially by stakeholders of the subsectors but is deemed overrated by experts and technology suppliers. Facilitating factors for implementation were also mentioned, e.g. regular refurbishment, additional benefits such as a better control and monitoring of appliances, and related synergies with energy efficiency measures. The recast of the EPBD (European Commission, 2018; Directive 2018/844) reinforces the readiness of buildings for DR and can thus support the diffusion of these technologies. This also relates to lower financial effort for technical equipment to realise DR in the future. Energy management, technological developments and changes in regulations can be seen as door-openers for DR, especially if a simplified prequalification and aggregation of potentials is necessary. Time-of-use tariffs could be another option to bypass the participation criteria and barriers of the flexibility markets. Under the premise of increasing shares of renewable energies, changes in the energy system and a greater relevance of flexible demands, financial attractiveness might increase.

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

Following Chapter IV, a deeper investigation of the selected target groups offices, trade and hospitality to quantify their flexibility potentials is warranted. Currently, the potentials are rarely used, only a small share of companies check their flexibility options or conduct DR. The results confirm the findings from the qualitative study, identifying large companies in general and particularly restaurants and retail food as the subsectors with higher interest in DR. Those company types are also the ones with the highest willingness to conduct DR measures. The quantitative evaluation comprises the theoretical potential (representing the energy demand of flexible appliances) the

technical potential (considering technical restrictions of the appliances to make their demand more flexible), and the practical potential (taking the companies' willingness into account). The considered flexible cross-cutting appliances are ventilation, air conditioning, cooling and refrigeration, heat pumps, night storages and electric water heating. Overall, the subsectors retail food and restaurants have the highest theoretical, technical and practical potentials. The highest shares of flexibility can be provided by air conditioning, and cooling (fridges and cooling rooms). Our assumptions on technical restrictions are very conservative, assuming a technical potential of 1-2 hours per appliance per day. The overall technical potential of our selected sectors is almost 20% of the theoretical potential. Regarding only the companies that stated their willingness to conduct DR, the practical potential is still about 25% of total technical potential. Differences between the appliances regarding the willingness to use them for DR can be expected: the flexibilisation of ventilation and air conditioning is relatively highly accepted; cooling appliances seem to be less critical to use than refrigeration devices. With the inclusion of all other flexible appliances in the subsectors described, 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 "first mover" potential. The willingness (i.e. the intention to conduct DR) depends on the conditions and related drivers and barriers. Especially the perceived importance of DR for the energy transition, the suitability of appliances for DR, the financial attractiveness and the risk of measures being disruptive to internal processes play an important role. They reflect the attitude, technical requirements, economic attractiveness and organisational suitability of DR. Financial issues and attitude play a stronger role for small companies, assuming a relation to their smaller potential per company. For larger companies, especially technical constraints influence the willingness to conduct DR. Besides the general willingness, the prioritisation of DR by management is also important for decision-making. Here, especially the positive image effect related to DR and the organisational effort of measures play a role. Additionally, having conducted an energy audit (i.e. having experiences with energy measures) increase the priority of DR in a company.

Chapter VI: The flexibility deployment of the service sector – a demand response modelling approach with evidence from a market research study

The focus of this chapter is on the technical and practical flexible demand that can actually be deployed. Compared to the potentials that can be provided by the companies, this approach takes the perspective of the flexibility required, assessing the match of potentials and needs for flexibility in the electricity system. The match is calculated by taking load curves of the available flexible appliances and the residual load curve into account, also considering e.g. the generation by renewables, weather conditions and developments of energy consumption. The estimates are made assuming the same consumption data for flexible appliances as in Chapter V and a scenario with 50% share

of renewable energies, i.e. the target share for 2030.
If all selected subsectors participate in DR, a technical flexibility deployment of 7.7 TWh can be achieved, the largest technical flexibility deployment can be made in the sectors trade (3.4 TWh) and hospitality (2.6 TWh) and with the appliances ventilation and air-conditioning (VAC, 2.8 TWh) and cooling/ refrigeration processes (2.6 TWh). As the technical potentials are not restricted to 1-2 hours for each appliance per day, but derive from the consumers' electricity consumption behaviour, the calculated deployable flexibility of electricity is higher than calculated in Chapter V. Considering developments until 2030, some potentials might turn out to be smaller, since the electricity consumption of appliances might decrease. The deployability of the flexibility varies depending on weather conditions and seasons. While AC is only available in the summer months, heating appliances like night storage heaters and heat pumps are not operated in the hot summer season. The availability of flexibility partially coincides with renewable energy sources (RES) surplus: about 20% (0.5 TWh) of the total RES surplus of 2.5 TWh could be absorbed by the sectors considered. In a further scenario with 80% RES (which may be the minimum RES share by 2050 in many countries), the availability of flexible loads matches the RES surplus more often and about 1.6 TWh can be absorbed by our selected sectors. If only the companies that stated willingness to participate are taken into account for the 50% RES scenario, the consumption of flexible appliances is reduced to 16.5%. This reduces the practical flexibility deployment to 1.8 TWh (24% of the technical flexibility deployment) and only 0.1 TWh of RES surplus (26% of the technically feasible reduction) can be absorbed by the selected sectors. However, it can be assumed that the willingness to participate in DR might increase in the period leading up to 2030, when the value of flexible demand rises, and technical standards and the controllability of appliances facilitate the use of flexibility potentials. Assuming that the price of electricity depends on the residual load, the future real-time electricity price using the residual load of 2030 including a share of 50% RES can be calculated. Due to small spreads on average between two consecutive hours, the financial value of a deployed flexible MWh of electricity is estimated at €23.

Chapter VII: How much load flexibility can a euro buy? Findings from a choice experiment with companies in the German commerce and service sector

In addition to the service sector's demand flexibility potentials and their deployability, the survey data allowed us to learn more about the willingness of accepting demand response dependent on payments. The companies that stated a general willingness to participate in DR were invited to participate in a choice experiment. They were randomly asked about a flexible appliance and if they would agree to automatically control it for means of DR if they received a compensation payment. Each company was presented with two of these scenarios, i.e. was asked regarding two different appliances. The scenario varied in frequency (between twice a day and once a week), duration (between 30 and 90 minutes) and timeframes (at any time vs. only at agreed time slots)

of the automatic control. The experiment makes it possible to estimate indicative average costs per MWh to activate the companies' economic flexibility potentials for the appliances ventilation, air-conditioning, refrigeration and freezing. Many of the companies either generally accepted or generally neglected the offer in the experiment and the resulting payments spread considerably. It can be assumed that the companies lack market experience and thus are unsure about adequate payment and tend to either favour or refuse to participate in DR for reasons of strategy or attitude.

For ventilation and air conditioning (VAC), the average expected payment per year of the participating companies is about €1,400. For ventilation, the companies expected annual payments of €1,200 on average, for air conditioning about €1,700. No effect of duration and frequency was found, but if the flexibility is only demanded in agreed timeframes, the expected payments are reduced (about 1/3 lower). Comparing ventilation and air conditioning, air conditioning promises a larger and a more cost-effective potential. The potential is higher, but the expected payment does not differ much from the one for flexible ventilation. Taking the average electricity consumption (technical potential) of VAC of the companies participating in the experiment into account, the potential of ventilation appliances could be mobilised for about 800 €/ MWh and the potential of air conditioning could be unlocked for about 300 €/ MWh (assuming a flexible share of 4% of the electricity consumption for ventilation and 11% for air conditioning). For refrigeration and freezing, the mean expected annual payments are about €2,500, while the payment for flexible demand for freezing compared to cooling appliances needs to be considerably higher. If these numbers are put into relation to electricity consumption, the potential of refrigeration/ freezing could be mobilised for about 900 €/ MWh on average. Frequency, duration and timeframes did not have effects on these numbers, but larger companies require higher total subsidies.

Chapter VIII: Energy efficiency and demand response – two sides of the same coin?

A sustainable energy system needs to include energy efficiency and flexibility. Thus, it is of interest to find ways to promote both concepts in synergy. From the perspective of companies, both concepts are related because they aim at influencing their energy consumption, but regarding practical implementation they present them with different challenges. Across all subsectors, energy efficiency measures are much more common (in about 50% of the service sector companies) than demand response measures (less than 10%) and the shares are highest in large companies and those from the hospitality subsectors. Energy efficiency (EE) measures are conducted across all cross-cutting appliances and most often regarding lighting and sensors, heating and IT/ energy management. 17% of companies that implemented EE measures stated that at least one of the measures was funded or financed by the German federal government or –state (*Bundesländer*) incentives. Demand response (DR) measures are usually used for internal optimisation of demand, like load shedding or optimised purchasing of

electricity. Only 1% of the surveyed companies stated that they participate in the balancing markets. Certain factors affect and support the implementation of energy-related measures (e.g. audits, energy management systems or building management systems etc.). The same company types that implement either EE or DR measures are those companies that use building or energy management systems and conduct audits. The analysis revealed that most of these factors positively influence the probability of conducting both measures. Nevertheless, company characteristics such as sector and size are more relevant for conducting DR measures than EE, indicating that DR better fits certain types of companies, while EE is less specific. Energy efficiency measures usually require a change towards more efficient appliances or more modern systems, DR measures might imply a change in individual standards or routines, e.g. when tariffs are changed, or contracts need to be negotiated with service providers. The relevant factors and the drivers with the highest influence resp. barriers are the same for DR and EE, yet DR measures are less established and start at another level of practice compared to EE. Both kinds of measures can be seen as measures influencing energy demand and are not perceived completely differently by companies. This suggests that instruments successfully promoting energy efficiency measures could also work to promote demand response.

Established types of energy efficiency policy instruments were examined regarding whether aspects of demand flexibility can be transferred or integrated. Some instruments already implicitly support demand response measures, e.g. incentives to implement energy management systems or directives promoting increasing the "smartness" of a building, aiming at an efficient and comfortable operation of the building, its ability to connect to electric vehicle charging, and to support demand response in a modernised electricity market. Other instruments can basically also be applied for the promotion of DR, such as audit obligations and other informational instruments (e.g. Energy Efficiency Networks), ideally combined with financial support for the identified measures. Standardising measures could also start at appliances, having a standard for "DR ready" appliances comparable to efficiency standards. Due to the less developed regulatory framework and the stronger specificity of DR measures regarding company types, successful measures might need even more tailoring than EE measures. For companies thinking about participating in DR, the value of the flexible demand is more dependent on market offers and regulations, weather conditions, and the need for flexibility than for energy efficiency. Nevertheless, experiences with EE can work as an enabler to implement other energy related measures and profit from synergies, e.g. by using energy management systems already available.

1.2 Answers to the research questions

In the following sections, the results of the individual chapters are brought together and condensed to answer the research questions.

1. *How can energy efficiency measures successfully be implemented in companies and which determinants need to be considered?*

Suggesting profitable measures and supporting companies in all phases of the decision-making and implementation of measures has proven to be advantageous for a successful process to improve EE. In such a manner, most of the relevant barriers and expectations regarding motivation, profitability and information can be addressed. The support enables companies to deal with different challenges that occur at different stages of the process. Sharing experiences and comparisons with other companies increases motivation and offers orientation. Barriers are also specific for measures and company characteristics, especially for size and sector that determine the energy-intensity and availability of technologies and facilities. Additionally, factors such as the autonomy of the enterprise, relatedness to customers, and decision-making processes play a role. Good implementation procedure considers this necessary fit and the specific needs of the companies. The main categories of barriers found in the literature could be confirmed, i.e. technical, organisational, economic, behavioural and external, while barriers associated with time and money are often ranked highest. To mitigate the risks of early failure if measures are neglected because they are mistakenly presumed not to be profitable, it should be possible to identify the suitable and profitable measures with only a low effort extended.

General success factors are:

- Easily available information and support at any stage of decision-making/ implementation, because different barriers and challenges occur at each stage;
- Structural characteristics of the company as well as economic, technical, behavioural/ motivational and external/ information-related barriers need to be considered;
- The implementation of measures can be facilitated through the following approaches:
    - thresholds to energy-related measures should be lowered: audits, energy management systems and the installation of control technologies of energy consuming appliances can function as door openers;
    - when a person in charge is responsible for energy issues in the company and when decisions about energy measures can be made internally, the decision-making and implementation process is usually smoother;

- in decision-making, unfavourable profitability benchmarks such as short payback-periods can impede measures; long-term and non-energy benefits should also be considered to increase the value of measures;
- the effort expended should be kept low for the company:
  - establish a self-assessment tool for the first screening of potential measures that fit the expectations and characteristics of the company;
  - provide services or one-stop-solutions for the identification and implementation of measures.

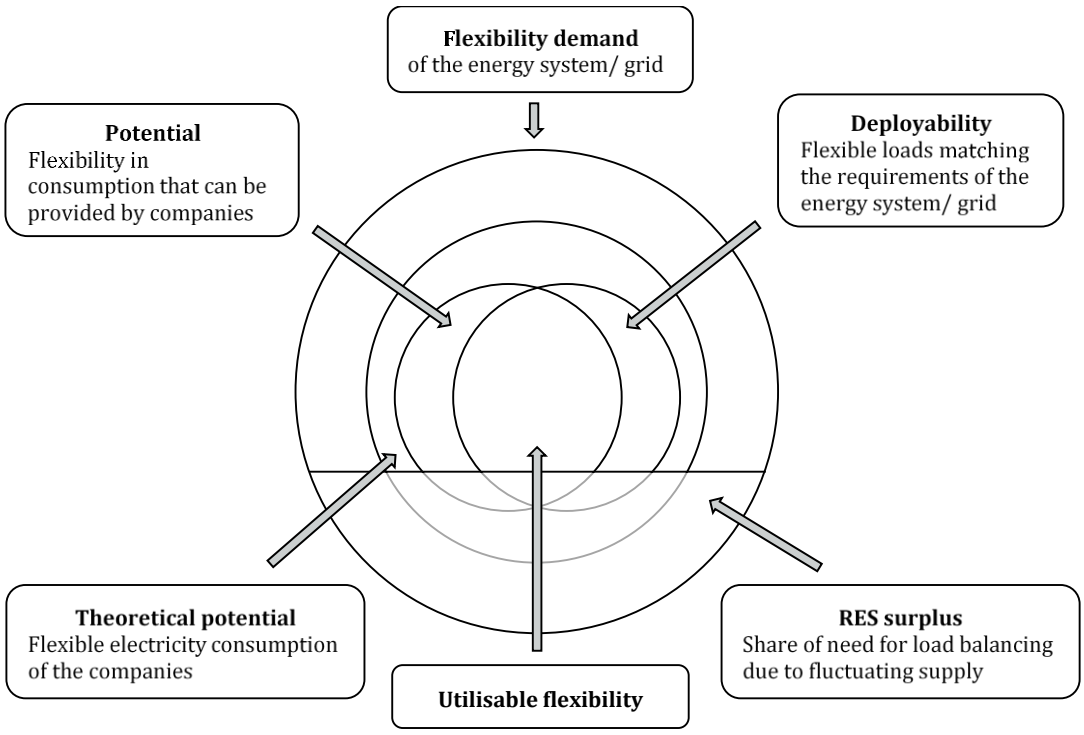
2. *Which companies of the service sector are target groups for demand flexibility and how big is the potential?*

At present, the potential in the service sector is largely untapped, unlike in the industrial sector. In addition to the energy-intensive companies those with flexible energy consuming appliances not part of the core business (and therefore less critical when used for DR purposes) could be of special interest for DR. Due to the homogeneous distribution of service companies across the country, their potential could complement regionally focused DR in the industry sector. Additionally, as the service sector accounts for about 30% of the German electricity demand, it could play an important role for DR and might even gain more importance given the ongoing development towards a service economy. The first step to identify target groups in the service sector was to select the subsectors with the high shares of electricity consumption, especially those subsectors where flexible appliances are the origin of a high share of this consumption. The subsectors offices, trade and hospitality (hotels/ restaurants) together account for more than 50% of the total electric energy consumption of the whole sector. 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. Appliances with flexible consumption are ventilation, air conditioning, cooling and freezing next to electric water heating, night storage heaters and heat pumps.
When estimating the flexibility potentials different analytical dimensions were considered, defining the theoretical, technical, economic and practical potentials. The availability of flexible appliances determines the flexible energy consumption, i.e. the theoretical potential; the technical restrictions of making the demand more flexible influence the technical potential. These technical restrictions are expressed e.g. by the duration and frequency with which appliances can be used flexibly in favour of DR without risking a negative impact on productivity. The practical potential is determined by the willingness to conduct DR. Besides the potentials that represent the available flexible demand, the deployability of these potentials is also taken into account, i.e. the timing and matching of availability and needs for flexibility. The results derive from optimisation model runs

(assuming a share of 50% renewable energies, using generation and consumption profiles). Figure IX-1 shows the relation between the concepts of flexibility demand, potential and deployability.

Figure IX-1: Illustration of flexibility demand, potential and deployability

Depicted sizes of the concepts do not relate to realistic relations



Restaurants and trade (food) sectors have the highest electricity consumption in flexible appliances and therefore the highest theoretical potential. For the sectors considered, especially the flexible appliances air conditioning and cooling appliances (fridges and cooling rooms) cause the highest electricity demand. It should be mentioned that the appliances also differ in how they can be utilised for different purposes, e.g. AC and refrigeration processes both have high DR potentials, but AC is used in predefined timeframes and refrigeration is used continuously. AC turned out to best match the requirements of RES integration due to its load profile, but the need for AC in specific timeframes makes it more sensitive if automated deployment of flexibility is performed without predefined timeframes. Refrigeration could be more easily controlled automatically, but the process is generally more critical than AC.

The results of our estimates are found in Table IX-2. The theoretical potential is the total consumption of flexible appliances in the sectors mentioned and accounts for about 35% of total electricity consumption of the subsectors. The technical potential varies depending on the assumptions concerning to which extent the appliances can be used flexibly (scenarios

A and B). The technical deployability is closer to scenario B, i.e. the acceptance of a more intense use of the appliances for DR purposes is a stronger restriction on the deployability of flexibility than the need for flexibility of demand. The flexibility that can be used to smoothen the residual load is estimated at 0.5 TWh. The practical potential and the practical deployability only take into account the companies willing to participate in DR.
It is difficult to estimate the economic potential as there are currently few options for the service sector to trade its flexible demand. Future developments suggest an increase in value, but the marketing opportunities still need to be developed. Modelling price signals as market-based incentives result in possible gains of 23 €/MWh. The modelled deployment of flexibility is market-based and is supported by modelled price signals from a spot market. Other (mainly grid-based) incentive systems, and possible future incentives for flexible behaviour, such as variable grid tariffs, could feature higher potential revenues. The revenues on the balancing markets today are about 400 - 700 €/ MWh but cannot yet be accessed by the service sector. The payments expected by the companies depend on the details of the procedure to make the appliances flexible and the features of the appliances but can be estimated to fall within a comparable range of about 300 - 900 €/ MWh.

Table IX-2: Summary of flexibility potentials and deployment

		Unit	VAC	RF	HW	HP	NSH	Total
Potential ("available" flexibility)	Theoretical potential (electricity consumption)	TWh	7.83	9.27	2.90	0.30	1.79	22.09
	Technical potential Scenario A	TWh	0.45	1.20	0.36	0.02	1.79	3.82
	Technical potential Scenario B	TWh	1.6	2.4	0.36	0.04	1.79	6.19
	Practical potential (A)	TWh	0.14	0.43	0.08	<0.01	0.29	0.90
Deployability ("required" flexibility)	Technical flexibility deployment	TWh	2.75	2.64	1.22	0.13	0.99	7.74
	Practical flexibility deployment	TWh	0.65	0.64	0.30	0.03	0.20	1.82
	(Technical) reduction of RES surplus electricity	TWh	0.18	0.14	0.01	0.07	0.10	0.51
	Expected economic revenue	€/MWh	800/ 300	900	n/a	n/a	n/a	n/a

VAC: Ventilation & Air Conditioning, RF.: Refrigeration, HW: Hot Water, HP: Heat Pumps, NSH: Night Storage Heaters
Scenario A: 1-2 hours flexible operation per appliance and day, Scenario B: doubled flexible operation (for details cp. Chapter V).
The numbers are partially derived from the original data and are not presented in the papers in the same degree of detail.

3. *Which determinants influence that flexibility potential in companies of the service sector?*

As explained previously in the introduction, especially technical, organisational, economic, behavioural and external determinants frame the analytical dimensions to assess influencing factors on the adoption of energy-related measures. The dimensions are partially interrelated, and each can comprise impeding or supporting aspects influencing the potentials of companies towards adopting measures (cp. Figure IX-2). Having control over these factors opens up the possibility to make use of driving forces and to reduce barriers to fully tap the DR potentials.

The following aspects were identified as relevant regarding making the demand in companies (more) flexible:

- **Behavioural dimension** – attitude and motivation of involved persons that influence behaviour
    - Positive attitude towards measures: being convinced that the measures are an important contribution to the energy transition turned out to be a significant driver for the adoption of energy-related measures.
    - Positive image effects on the customer: especially in sectors that have a close relationship with their customers generating a positive image can be a selling point for energy-related measures that might set the company apart from competitors.
    - Prioritisation of energy issues/ management is convinced: this aspect often is a precondition to deal with possible measures. Prioritisation is higher when energy measures are perceived to be strategic and is usually low if energy costs are low and small potentials are expected.
    - Comfort: the measures should not impair the comfort of employees or customers, since then the quality of work or service(s) could suffer. This aspect is closely related to the organisational dimension, e.g. work processes, business hours and operation of flexible appliances.

- **Technical dimension** – available flexible appliances, restrictions concerning their operation and supporting technologies
    - Suitability: the availability of appliances that can be operated flexibly. This aspect relates to organisational issues, determining the availability of sector- and size-specific appliances and the specifics of their operation.
    - Characteristics of the appliance: The characteristics influence the willingness of companies to use the specific appliance for DR, e.g. if the use of the appliance requires a continuous operation or if it is function is sensitive to switching on and off. Thus, using DR for AC is usually more accepted than for freezing appliances. On the other hand, the operation of AC is not a continuous process, i.e. it is more sensitive to interference as it is only needed in predefined timeframes. If the flexible operation of such an

appliance cannot be predicted or influenced, accepting its use for DR purposes is decreased. The usual operation of an appliance also determines the possible value of its flexibility, e.g. if the appliance is flexibly available when flexibility is needed in the system.
    - Energy management systems/ building management or control devices: these support technologies facilitate the identification of measures, controlling appliances and decrease initial costs and effort.

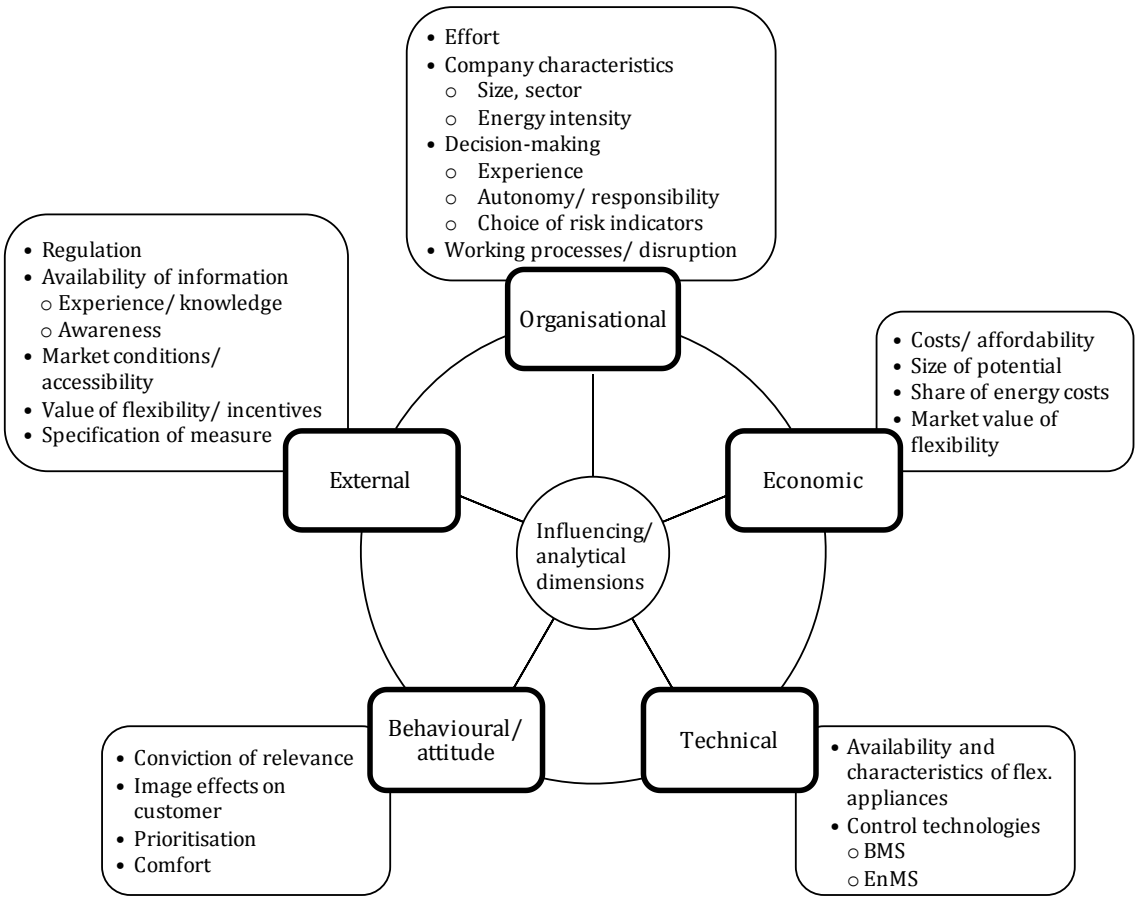
- **Organisational dimension** – internal processes, responsibilities and work processes
    - Company characteristics: Size and sector of a company determine energy intensity, core business, available appliances and whether there are persons in charge of energy issues.
    - Decision-making processes: An energy manager that takes on the responsibility to encourage energy-related measures is usually favourable for implementation. If the company is not authorised to make decisions on its own (e.g. because of being part of a parent company or not owning the appliances), the implementation of measures can be impeded. In case of chains, centralised decision-making can facilitate and accelerate roll-out, which can be especially interesting for aggregating loads for DR and for reducing transaction costs.
    - Working processes: Using appliances flexibly bears the risk of disruption of processes. This barrier is ranked lower in the service sector than in industrial companies, because the flexible appliances usually are not part of the core business. Nevertheless, the operation of appliances can interact with work processes or habits of employees/ customers.
    - Effort: A high organisational effort usually decreases the intention to adopt measures and is associated with costs. The effort needed to make use of the flexible potentials of a company interacts with technical (e.g. availability of control technologies), organisational (persons in charge of energy issues) and motivational (e.g. the willingness and prioritisation) aspects.
    - Energy intensity/ consumption: In companies with a low energy intensity, the share of energy costs is usually small, and the relevance of energy issues is low too. This aspect interacts with motivational aspects towards adopting measures.
    - Experience: Experiences with other energy-related measures can increase knowledge concerning energy consumption and facilitate the identification of potentials and competent selection of measures.

- **Economic dimension** – financial aspects concerning profitability and costs
  - Profitability: Profitability is not independent from framework conditions (e.g. regulation and market access). The profitability is influenced by the following potential factors:
    - measures/ necessary equipment are too costly or not affordable,
    - energy costs,
    - poor assessment of profitability ,
    - expected profit relative to effort/ risk ,
    - small value of flexibility/ lack of (regulatory) incentives (e.g. if a constant consumption is better rewarded).

- **External dimension** – circumstances, regulatory conditions and market
  - Regulation: If the regulatory framework is unclear or even impedes and complicates participation in the markets, DR will not be taken into account. A non-incentivising regulation also lowers the profitability of measures.
  - Market access: Participating in the balancing market is complicated or hardly possible especially for small energy users.
  - Information: The availability of information is influenced by the stage of development of the market and standardisation of processes or accessibility to markets, especially if the allocation of information takes a lot of effort and if experience is rare. Unlike energy efficiency audits, there is no comparable information on flexibility potentials for companies.
  - Awareness: Awareness is closely related to the availability of information and the motivation and experience of a company regarding energy issues. DR is not common in the service sector and almost 50% of the companies have not yet heard of it. This makes it harder to tap the potential.
  - Specifications of the measure: Specifications influence the acceptance of making the demand flexible and relate to the appliance and company characteristics but are also part of the contract with a service provider. E.g. if the operation of an appliance for DR purposes has no notable impact or is predictable, a company is more likely to adopt the measure.

The results showed that different stages of decision-making affect the relevance and the ranking of barriers. Especially technical and economic aspects and effects on work processes are relevant for practical implementation while behavioural and organisational aspects influence the prioritisation of DR, i.e. if the company is interested in dealing with the measures.

Figure IX-2: Influencing factors of energy flexibility (DR) measures

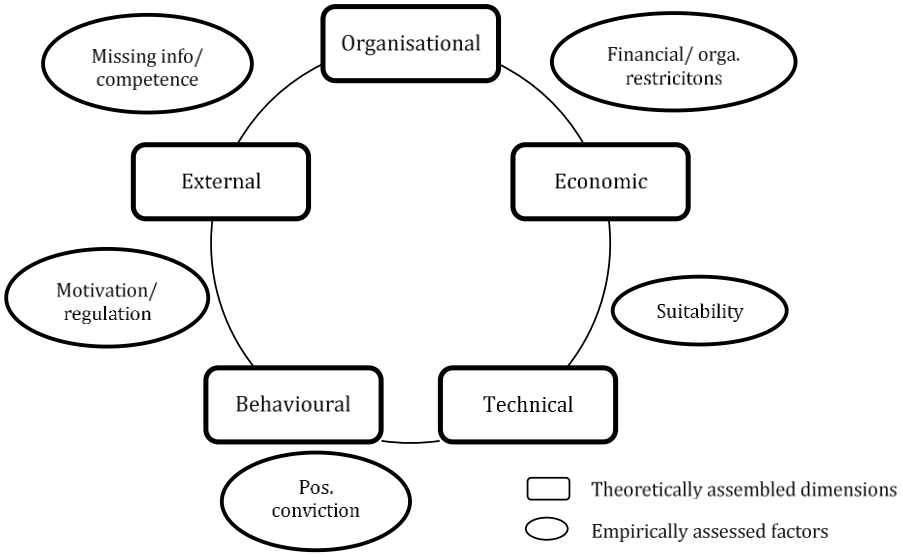


4. *How can we make use of synergies between demand flexibility and energy efficiency?*

Both energy efficiency and demand flexibility contribute to the main pillars of the energy transition and thus have the same goal. From the perspective of companies, there is a relation too – both require a change in the consumption pattern. While energy efficiency means a reduction of consumption or increasing productivity, demand flexibility means a change of the consumption pattern by lowering or increasing the consumption dependent on electricity generation or volatility. Thus, in the specific case, the concepts may counteract each other, e.g. if consumption is reduced to a minimum, the flexibility potential is reduced. If processes run most efficiently, making demand more flexible might reduce efficiency. Which concept is more favourable regarding the efficiency of the energy system depends on the energy generation and grid stability situation , e.g. in case of a surplus of renewable energy sources, shifting demand to these times is worth more than energy savings and in case of grid instability not using available energy can even be favourable. Consequently, the value of energy efficiency and/ or demand flexibility depends on the point in time. While energy savings or efficiency pays off by reducing costs, demand flexibility needs to be incentivised externally. Nevertheless, enabling companies to implement both is favourable.

The assumption that EE and DR face comparable drivers and barriers could be confirmed, although differing in detail. Compared to the generalised taxonomy, the factors assessed empirically (cp. Chapter VIII) lie diagonally to the theoretically assembled ones (cp. Chapter I), reflecting the interrelation between the dimensions. However, they show the same emphasis and some of these factors also influence the adoption of measures in a comparable way (Figure IX-3).

Figure IX-3: Empirical confirmation of analytical dimensions of energy related measures



Hence, it stands g to reason to use experiences with EE to promote DR, especially as flexibility potentials are rarely used so far, and policies and regulations are relatively underdeveloped. Some successful policy instruments could be extended or transferred to also cover DR. Energy efficiency audits (informational policy instrument), for example, turned out to have a significant influence on adopting energy efficiency measures. If an evaluation of flexibility potentials was included into the audits, DR could also be supported. The same goes for Energy Efficiency Networks (educational/ training policy instrument) that could also work as DR networks, possibly with the option of finding partners within the networks to aggregate loads. Funds or subsidies (financial policy instruments) can help to remove the barrier of investment costs for necessary technologies, like e.g. energy management systems or building management. These ancillary technologies also increase the smartness indicator of the building (cp. EPBD) and could be promoted with labelling standards for smart technologies (information regulation). Using a label to increase the visibility of measures could also enhance image effects and act as a driver. A more detailed evaluation of transferrable policy measures can be found in Chapter VIII. The general regulatory instruments regarding marketing options of demand flexibility and market access still need improvement and interact with a reshaping of the markets, e.g.

introduction of new actors and service providers. To start the roll-out of utilising DR potentials, comparable target groups as for EE come into play – companies with high energy consumption and ancillary control technologies already available that are well informed about their energy consumption and the runtimes of their appliances. Thus, EE can function as an enabler for DR.

1.3 Conclusions and recommendations

This thesis investigates success strategies for the implementation of energy-related measures (energy efficiency and demand flexibility), dealing with the dimensions that influence the potential of adopting such measures. An identification of target groups and a broad and detailed evaluation of theoretical, technical, economic and practical potentials of demand flexibility in the service sector is presented. To use the potentials policy recommendations based on these results are derived to pursue both improving energy efficiency and demand flexibility.

1.3.1 Conclusions

Influencing factors

In all phases of decision-making, from the identification of suitable measures to the practical implementation, different dimensions need to be considered to identify the factors determining the successful adoption of measures. The taxonomy of barriers to energy efficiency was confirmed in this thesis and successfully applied to demand response. Additionally, attitudinal aspects of significant influence that can complement the existing dimensions of the taxonomy were identified and a new and more general taxonomy for energy-related measures is proposed.
The assessment of the rating of influencing factors and their effects on the intention to implement measures showed that one needs to distinguish between barriers with high rating (indicating their occurrence) and the relevance of influencing factors (indicating the strength of their effect on the intention towards or implementation of measures). The analytical dimensions identified cover the important influencing factors for energy-related measures in companies. The potentials of energy-related measures were proven to be sensitive with regards to the influencing factors and also their relevance was found to differ in relation to the specific case, e.g. depending on company-type, kind of measure/ related technology, phase of decision-making. These findings help to better harmonise measures and target groups and to design supporting instruments for successful implementation.

Potentials

Different kinds of potentials need to be distinguished. In this thesis, the theoretical, technical and practical potential on the level of subsectors of the service sector and cross-cutting appliances are presented. As mentioned previously, the market access to trade their flexibility and other options to financially make use of the potentials is limited in number for companies with small loads. Thus, a scenario to assess the economic potentials resp. the expected payments stays hypothetical. The choice experiment used in Chapter VII is a method where a case to participate in demand response is described as concretely as possible, for the answers given to be as realistic as possible. Nevertheless, the results can only be generalised to a limited extent. Due to the limited experience of the companies in this area and unclear regulatory aspects, the estimated expected payments are indicative. It can be said that they are more sensitive to the predictability than to the duration or frequency of an intervention for DR purposes and differ between appliances. Our methods to estimate the theoretical and technical potentials and their deployability comprise bottom-up calculations based on empirically assessed consumption data and availability of appliances resp. optimisation modelling. These estimates resulted in 17-25% of the flexible electricity consumption being able to be provided by the companies for DR (technical potential) and about 35% could technically be deployed. The lower technical potential depends on cautious assumptions concerning to which extent an appliance can be used for DR purposes without decreasing or risking to forgo its functionality. The modelling approach resulted in a higher technical deployability, indicating higher potentials if these technical possibilities and aspects of comfort and acceptance are stressed more strongly. From this point of view, the lines between the technical and the practical potential blur and the concepts cannot be considered independently.

Practical implementation

Although DR in the less energy-intense sectors is uncommon, the wheel does not need to be reinvented to find means to promote demand flexibility. Many successful policies can be transferred from EE policies or serve for EE as well as DR, as EE and DR measures may even create synergies. For effective policies, the framework conditions (including associated regulation) need to change in order to make DR more attractive. It can be assumed that the relevance will increase with higher shares of renewables, but cornerstones can already be laid by promoting control technologies, management systems and automation. Compared to the larger potentials per company in the energy-intensive sectors, the less energy-intense, but regionally distributed companies could take advantage of their availability of flexibility on the level of distribution grids.
Whether a company, appliance or process is better qualified for EE or DR measures depends on a variety of factors: High loads indicate a high potential for both, but the deployability is determined by company and technology characteristics. These determinants can be described similarly for EE and DR. An energy-intensive process that

is needed at a specific time, is unpredictable or cannot be interrupted is not suitable for DR but can be for EE. While the efficiency of a process can be improved by using more efficient technologies, DR is more specific and requires changes of the processes itself. The consequence of this is that the differing suitability of appliances for DR or EE needs to be taken into account when potentials are assessed.

1.3.2 Outlook and recommendations

The theoretical taxonomy and classification of barriers is widely accepted and confirmed, with methods comparable to those used in this thesis. To reliably determine details of these influencing factors and their influence on decision-making and implementing energy-related measures, good evaluation instruments are needed. The factor analysis to extract the main influencing factors resulted in satisfying categories, but depending on the context, there were difficulties in clearly assigning the factors to the various dimensions. Future research could focus on developing tools to systematically assess the main analytical dimensions for energy-related measures. Methods of test theory and item construction can be used to develop distinct and standardised scales with high quality criteria for validity and reliability.
The results found in this thesis made the relationship between influencing factors and their relevance against the background of company characteristics, measures and phases of decision-making evident. Studies dealing with potentials in energy-related measures and their implementation should always seek to use a holistic approach, taking all these dimensions into account. The categorisation proposed in this thesis can help to improve the evaluation of potentials in this manner and form the basis for the development of standardised scales.

The connection between the technical and the practical potential implies that e.g. control technologies can help maximising the technical potentials by completely seizing the opportunities offered by technical possibilities and by using technical solutions to tap a larger practical potential without losing the willingness to use the potential, i.e. the potentials increase and the difference between the technical and the practical potentials decreases. The maximum potential can be exploited when more details are known concerning the acceptability of specific measures. The general willingness to participate in DR is crucial, but the acceptability to adopt a certain measure also depends on details such as the individual appliance, company characteristics and the details of the concrete implementation (e.g. predictability of the intervention). The expected financial revenues are higher if the measures are accompanied by discomfort or disadvantages. A more precise determination of the economic potential therefore also depends on incentives, e.g. the development of business models, regulations and the particular design of measures and requires further research.

Fortunately, willingness can be increased by designing advantageous conditions, using the findings on the relationship between influencing factors and willingness. The assumptions made in this thesis to estimate technical flexibility potentials and deployability are based on other literature but are not necessarily derived from practical experiences. Thus, the trade-off between using flexibility most effectively one the one hand and maintaining acceptable levels of routine and comfort on the other hand needs to be evaluated. Field studies can evaluate various scenarios to gain more experience and better determine the practical potentials via realistic measuring in the identified target groups.

When energy-related measures are considered in companies one main issue, especially in less energy-intensive companies, is the fact that energy is not their core business. For measures to be implemented they need to gain a strategic value. While a lot of research is done on barriers towards such measures a successful implementation needs to highlight potential drivers, e.g. improved controllability of appliances and concomitant increased comfort and the possibility to improve the company's image in the eyes of its customers. The latter was found to be relevant in the service sector, as well as the attitude towards measures and their perceived relevance for the energy transition. These non-energy benefits could be relevant especially if economic incentives are small.
In decision-making for a specific energy-related measure, whether EE or DR is worth more depends on the grid and supply situation. Additionally, different grid- or market-driven situations can counteract each other, e.g. if demand flexibility is needed to ensure grid stability or the integration of renewable energies. To respond to these situations appropriately a unified incentive tool for the market participants needs to be developed, e.g. a variable tariff that already considers the specific situation and thus implies a prioritisation of system requirements by incentivising the favoured demand response. This, in turn, requires clarity of priorities and a harmonisation of regulations.

2 Samenvatting en conclusies

De energiestrategie van de EU voor de lange termijn is gericht op een welvarende, moderne, concurrerende en klimaatneutrale economie tegen 2050, met als doel in overeenstemming te zijn met de doelstelling van het Akkoord van Parijs om de wereldwijde temperatuurstijging onder de 2°C of zelfs nog strikter tot 1,5°C te doen dalen. Energie-efficiëntie en de verhoging van het aandeel van hernieuwbare energiebronnen vormen sleutelelementen van deze visie.

Verbetering van de energie-efficiëntie vormt al decennialang een probleem, maar desondanks is het potentieel nog lang niet uitgeput en haalt Duitsland zelfs voor 2020 haar doelstelling voor het reduceren van het verbruik. Duitsland heeft tot nu toe goede resultaten geboekt bij de integratie van hernieuwbare energie, maar het toenemende aandeel zal leiden tot uitdagingen voor het beheersen van de volatiliteit van het toevoer. De regelgeving voor het gebruiken van het flexibiliteitspotentieel ter ondersteuning van de integratie van hernieuwbare energiebronnen is nog steeds onderontwikkeld. Het is duidelijk dat er nog steeds leemten in de kennis over het benutten van het potentieel inzake energie-efficiëntie en de vraag naar flexibiliteit bestaan, waarbij praktische ervaringen van bedrijven momenteel gering zijn.

Om deze leemten in de kennis op te vullen, wordt in deze proefschrift de nadruk gelegd op het onderzoek naar mogelijkheden voor het bijdragen aan de energietransitie door middel van het verbeteren van de energie-efficiëntie (EE) en de flexibiliteit van de vraag (vraagflexibiliteit, VR). Bedrijven in Duitsland worden als voorbeeld gekozen om de mogelijkheden, bepalende factoren en uitdagingen te illustreren. Onder de bedrijven in Duitsland kan een aanzienlijk potentieel op het gebied van energie-efficiëntie en vraagflexibiliteit worden verwacht.

Dit proefschrift is gewijd aan de centrale vraag:

Hoe kunnen energie-efficiëntie en flexibiliteitsmogelijkheden bij bedrijven synergetisch worden gerealiseerd?

Om deze onderzoeksvraag te beantwoorden, worden in het proefschrift de volgende deelvragen behandeld:

OV 1 *Hoe kunnen energie-efficiëntiemaatregelen succesvol worden geïmplementeerd in bedrijven en welke bepalende factoren moeten in aanmerking worden genomen?*

OV 2 *Welke bedrijven vormen doelgroepen voor vraagflexibiliteit in de dienstensector en hoe groot is hun potentieel?*

OV 3 *Welke bepalende factoren beïnvloeden dit flexibiliteitspotentieel in bedrijven in de dienstensector?*

OV 4 *Hoe kunnen we gebruik maken van synergiën tussen vraagflexibiliteit en energie-efficiëntie?*

De basis voor het beantwoorden van deze onderzoeksvragen wordt gevormd door zeven onafhankelijke publicaties die het potentieel, de beïnvloedende factoren en de aanbevelingen van en voor de praktische implementatie van energiegerelateerde maatregelen in bedrijven evalueren.

Hoofdstuk II: Leernetwerken als enablers voor gefundeerde beslissingen voor het hanteren van het energie-efficiëntiepotentieel in bedrijven
Gaat in op de vraag hoe geïnformeerde beslissingen, die gericht zijn op het energie-efficiëntiepotentieel in bedrijven, mogelijk kunnen worden gemaakt.

Hoofdstuk III: Afstemmen van energie-efficiëntiemaatregelen op de doelgroepen - benaderingen met betrekking tot transversale technologieën en belemmeringen in de industrie
Onderzoekt hoe energie-efficiëntiemaatregelen op verschillende soorten bedrijven moeten worden afgestemd.

Hoofdstuk IV: Het bepalen van de koers voor respons op de vraag in de dienstensector
Beschrijft de regelgevingssituatie voor VR in Duitsland en geeft antwoord op de vraag waar de mogelijkheden liggen, gezien vanuit het perspectief van de belanghebbenden met betrekking tot de dienstensector.

Hoofdstuk V: Vraagrespons in de dienstensector - theoretisch, technisch en praktisch potentieel
Geeft een schatting van het VR-potentieel van bedrijven in de dienstensector en laat zien welke factoren van invloed zijn op het potentieel.

Hoofdstuk VI: De inzet van flexibiliteit in de dienstensector - een modelleringsbenadering van de vraagrespons met gegevens uit een markt-onderzoeksstudie
Richt zich op de mogelijke bijdrage van bedrijven in de dienstensector aan het beheer van de belasting en de integratie van duurzame energiebronnen.

Hoofdstuk VII: Hoeveel belastingsflexibiliteit kunt u met een euro kopen? Bevindingen uit een specifiek experiment met bedrijven in de Duitse handels- en dienstensector
Maakt een schatting van de verwachte financiële winst van bedrijven, die voortkomt uit hun flexibiliteit op het gebied van de vraag.

Hoofdstuk VIII: Energie-efficiëntie en vraagrespons - twee kanten van dezelfde medaille?
Bespreekt wat wij kunnen leren van het omzetten van energie-efficiëntiemaatregelen zodat deze ook de flexibiliteit van de vraag ondersteunen.

Tabel IX-1 geeft de inhoud en de zwaartepunten van de hoofdstukken weer.

Tabel IX-1: Overzicht van de hoofdstukken, onderzoeksvragen, hoofdthema's, aandachtspunten en methoden

	Onderzoeks vraag				Voornaamste thema's			Sectorale		Maatregelen		Benadering/analyses
Hoofdsruk	OV 1	OV 2	OV 3	OV 4	Potentiële	Bepalende factoren	implementatie	Industrie	Dienstensector	Energie-efficiëntie	Energie-flexibiliteit	Methoden
II	x				x		x	x		x		voor- en na-evaluatie
III	x					x	x	x		x		factoranalyse, significantietests, regressieanalyses
IV		x	x		x	x			x		x	kwalitatieve analyse van belanghebbenden
V		x	x		x	x			x		x	wiskundige benadering, regressieanalyses
VI		x	x		x		x		x		x	modelleringsbenadering
VII			x		x	x			x		x	keuze-experiment / voorwaardelijke waardering
VII	x		x	x		x	x		x	x	x	beleidsanalyse, verg. factoranalyse, regressie

2.1 Samenvatting van de resultaten

In dit hoofdstuk worden de belangrijkste resultaten van de publicaties met betrekking tot de onderzoeksvragen gepresenteerd en besproken.

Hoofdstuk II: Leernetwerken als een hulpmiddel om met kennis van zaken beslissingen te kunnen nemen voor het benaderen van het energie-efficiëntiepotentieel van bedrijven.

Hoofdstuk II analyseert de monitoringgegevens van meer dan 350 bedrijven uit de productiesector, die deelnemen aan de "Learning Energy Efficiency Networks" (LEEN). LEEN combineert aspecten van informatie (zoals audits), gedeelde ervaringen en gemodereerde leerprocessen en maakt een evaluatie mogelijk van de verwachtingen en barrières waar bedrijven mee te maken hebben, en van de manier waarop informatie, samenwerking en ervaringen het succes van de implementatie kunnen beïnvloeden. De bedrijven worden tijdens alle stappen voor het verbeteren van de energie-efficiëntie ondersteund, te beginnen met een analyse van de situatie en suggesties voor rendabele maatregelen. Een focus van de analyses ligt bij de verwachtingen en behoeften van de bedrijven en hoe deze kunnen worden vervuld.

De belangrijkste zorg van bedrijven ligt in praktische kennis en specifieke informatie, d.w.z. een analyse van de energiesituatie, opties voor het reduceren van energiekosten en informatie over specifieke maatregelen en technologieën, die als een uitgebreide inhoud van een audit kan worden gezien. De tweede plaats werd ingenomen door de verwachting, die betrekking had op beslissingsondersteuning en vermindering van de transactiekosten door het uitwisselen van ervaringen, die verder gaan dan die, die typische energieaudits opleveren. Wanneer wij de verwachtingen vergelijken met de vervulling ervan, zou zeer wel aan deze verwachtingen kunnen worden voldaan. Deelname aan de netwerken verminderde de barrières van ontbrekend energiebeheer en ontbrekende informatie of marktoverzicht. De economische aspecten van de maatregelen konden niet worden verbeterd. Ondanks het feit dat sommige beoordelingen van de belemmeringen niet verbeterden, hebben vrijwel alle bedrijven (96%) de voorgestelde maatregelen voor energie-efficiëntie geïmplementeerd en verklaarde 75% dat deze maatregelen zonder de netwerken niet zouden zijn geïmplementeerd. De kwantitatieve bewaking door de energiemanager en de raadgevende ingenieur leidde tot een gemiddelde jaarlijkse efficiëntieverbetering van 2,1% (in vergelijking met de gemiddelde efficiëntieverbetering in de industrie van ongeveer 1%). Naast de kwantificering van de resultaten hebben de bedrijven ook geprofiteerd van de netwerken door contacten te leggen met andere bedrijven, en hebben zij de mogelijkheid gekregen om samen te werken op het gebied van energievraagstukken of voor andere doeleinden.

Een toegevoegde waarde ten opzichte van andere informatieve consultaties zoals audits doet zich voor in het toezicht over 3 tot 4 jaar, omdat er op verschillende momenten in het proces verschillende barrières kunnen optreden. Naast een zuiver consultatieve of informatieve functie, vervullen de netwerken dus ook de rol van enabler en voorzien zij de bedrijven van de nodige ondersteuning en praktische kennis. Aangenomen mag worden dat de afstemming van het programma op de behoeften van de deelnemers een belangrijke succesfactor vormt voor het concept van de netwerken. Tegen deze achtergrond moet er rekening mee worden gehouden dat belemmeringen niet alleen verband houden met maatregelen, maar ook voortkomen uit de routines, processen en andere kenmerken van een bedrijf. Om het energie-efficiëntiepotentieel van bedrijven ten volle te benutten, moeten de maatregelen worden afgestemd op hun kenmerken en beperkingen.

Hoofdstuk III: Energie-efficiëntiemaatregelen afstemmen op doelgroepen - benaderingen met betrekking tot transversale technologieën en barrières in de industrie

In hoofdstuk III wordt nader ingegaan op transversale maatregelen en barrières op het gebied van energie-efficiëntie en hoe deze zich verhouden tot verschillende soorten bedrijven wanneer het gaat om het identificeren van doelgroepen. Hiervoor worden de belangrijkste belemmeringen en hun relevantie voor de verschillende soorten bedrijven geïdentificeerd. Dit opent de mogelijkheid om maatregelen of diensten op het gebied van energie-efficiëntie en bedrijven beter op elkaar af te stemmen en vergroot de kans dat maatregelen daadwerkelijk worden uitgevoerd.

Uit de analyses blijkt dat de barrières met betrekking tot de beschikbaarheid van tijd en geld het hoogst worden geprioriteerd, hetgeen een weerspiegeling vormt van de lagere prioriteit van energievraagstukken in verhouding tot de kerntaken van het bedrijf. Een categorisering van de belemmeringen heeft geleid tot de het gebruik van de hoofdcategorieën "financiële/economische beperkingen", "beperkingen op het gebied van technische/structurele omstandigheden", "motiverende/interne relevantie" en "informatie of externe marktgerelateerde tekortkomingen". Deze categorieën zijn vergelijkbaar met de in de literatuur gesuggereerde taxonomieën van belemmeringen. De hoogst geprioriteerde categorie, economische belemmeringen, heeft betrekking op de financiële mogelijkheden of de rentabiliteit van de maatregel, die afhankelijk is van de beoordeling van de rentabiliteit van de ondernemingen. Deze beoordeling wordt vaak gemaakt met behulp van ongeschikte risico-indicatoren voor korte terugverdientijden. Deze barrière is met name aanwezig bij bedrijven die beslissingen voornamelijk baseren op financiële aspecten of deel uitmaken van een concern en dus niet zelfstandig over investeringen kunnen beslissen. De op één na hoogst gerangschikte categorie (technische/structurele omstandigheden) kan worden beïnvloed door overleg, instrumenten voor energiebeheer of -diensten. Vooral bij grotere bedrijven, bedrijven met lage energiekosten of bedrijven zonder energie-intensieve processen zijn

motivatiebarrières relevant. Vooral de laatste kenmerken hebben betrekking op het kleine energie-efficiëntiepotentieel en kunnen dus demotiverend werken op maatregelen. Wanneer in verordeningen of richtlijnen onderscheid wordt gemaakt tussen bedrijfstypen, wordt dit onderscheid meestal gebaseerd op de grootte van bedrijven. Uit onze analyses is gebleken dat de kenmerken die verband houden met specifieke belemmeringen sterker en frequenter zijn voor het MKB (kleine en middelgrote ondernemingen, <250 werknemers) dan voor LE (grote ondernemingen), hetgeen wijst op een grotere heterogeniteit binnen het MKB. Het aantal geïmplementeerde energie-efficiëntiemaatregelen is hoger bij grote bedrijven, waarschijnlijk als gevolg van een grotere productielocatie en dus meer beschikbare faciliteiten en technologieën. Niettemin worden verschillende soorten bedrijven geconfronteerd met verschillende barrières en hebben zij meer kans om verschillende soorten maatregelen te implementeren.

De voorgestelde energie-efficiëntiemaatregelen moeten verband houden met de kenmerken van de onderneming en niet uitsluitend met de technische mogelijkheden. Gewoonlijk zijn veel maatregelen technisch gezien geschikt, terwijl er slechts enkele voor implementatie worden geselecteerd. Omvang en sector bleken relevante factoren te vormen, maar ook de autonomie van de onderneming, de verwantschap met klanten, de wijze waarop beslissingen worden genomen en de energie-intensiteit spelen een rol bij het vinden van passende maatregelen voor een onderneming. Om de implementatie te verbeteren, moeten barrières worden overwonnen. Tekorten op het gebied van tijd en geld lijken de eerste valkuilen te vormen, waar optionele maatregelen falen. Vooral als energie geen strategische kwestie vormt, zijn de incentieven voor grote inspanningen laag. Een meer vooruitziende beoordeling van de rentabiliteit van maatregelen en aantrekkelijke financieringsmogelijkheden kunnen deze kwesties positief beïnvloeden. One-stop-oplossingen zoals een energiedienst kunnen de organisatorische inspanning en de gebruikte tijd laag houden. Meestal kan de besluitvorming sneller verlopen wanneer deze binnen het bedrijf (in plaats van bijv. door moedermaatschappijen) plaatsvindt. Een zelfbeoordelingsinstrument voor bedrijven waarbij passende energiegerelateerde maatregelen op basis van voornoemde beïnvloedende factoren kunnen worden gescreend kan ook de inspanningen en de tijd die nodig zijn voor het bepalen van passende maatregelen tot een minimum beperken.

Hoofdstuk IV: Vaststelling van de koers voor vraagrespons in de dienstensector

Een flexibelere vraag naar elektriciteit kan een bijdrage leveren aan het uitdagen van de integratie van volatiele hernieuwbare energie. In vergelijking met industriële sectoren werd de dienstensector in mindere mate onderzocht. Vergeleken met industriële sectoren met een hoger energieverbruik en flexibiliteitspotentieel per bedrijf is het verhandelen van flexibiliteit moeilijker voor minder energie-intensieve bedrijven in de dienstensector. In Duitsland kunnen flexibele belastingen worden verhandeld op de balancerings- en spotmarkt.

Congestiemanagement kan worden gebruikt in het kader van de "Wet op afwikkelbare belastingen". Flexibele verbruiksbelastingen moeten zich vooraf kwalificeren (d.w.z. voldoen aan de technische eisen) om in aanmerking te komen. Onlangs zijn de minimumaanbiedingen aangepast om ook de deelname van kleinere belastingen (tussen 1 MW en 5 MW) mogelijk te maken en kunnen belastingen worden gebundeld, bijvoorbeeld door derde partijen zoals aggregatoren. De gestandaardiseerde processen voor contracten tussen aggregator, balanceringsmanagers en leveranciers zijn echter nog niet duidelijk gedefinieerd en vormen een wettelijke belemmering. Bovendien vormt de "Electricity Network Charge Ordinance" (StromNEV) een aanvullende regelgevende belemmering voor het gebruik van het VR-potentieel, die de flexibiliteit van de vraag tegenwerkt door een consistente en voorspelbare vraag te stimuleren. Zo hebben met name grote energie-intensieve bedrijven (d.w.z. de industrie) of derde partijen (bv. virtuele elektriciteitscentrales) bovengenoemde markten betreden. Veel kleinere verbruiksbelastingen voldoen nog steeds niet aan de prekwalificatiecriteria. Pooling vormt een optie, maar is momenteel zelden nuttig. Sommige grotere ondernemingen uit de dienstensector gebruiken hun flexibele vraag om piekbelastingen tot een minimum te beperken, flexibele tarieven te hanteren of de inkoop van elektriciteit te optimaliseren. Daarom kan worden aangenomen dat het VR-potentieel van de dienstensector grotendeels onbenut blijft, maar waardevol kan zijn voor het beheer van het net of voor de ondersteuning van de integratie van volatiele hernieuwbare energiebronnen.

De subsectoren handel, restaurants, hotels en kantoren blijken de meest veelbelovende subsectoren te zijn. Samen zijn ze goed voor meer dan 50% van het totale elektriciteitsverbruik van de tertiaire sector. Een aanzienlijk deel van het elektriciteitsverbruik in deze subsectoren wordt veroorzaakt door apparaten die flexibel inzetbaar zijn. Deze flexibele transversale toestellen worden gebruikt voor koeling, verwarming, airconditioning (AC) en ventilatie, en elektrische warmwaterverwarming. Er wordt rekening gehouden met bevindingen uit interviews met belanghebbenden om meer te weten te komen over de wijze waarop de flexibele vraag in de geselecteerde doelsectoren kan worden benut. In kantoren is VR tot nu toe niet aan de orde, maar vooral op het gebied van AC en ventilatie is er potentieel te vinden. In grote, moderne gebouwen zijn reeds besturingstechnologieën beschikbaar die het gebruik van de flexibele vraag kunnen vergemakkelijken. De geïnterviewden wezen erop dat de maatregelen niet mogen interfereren met de behoeften van de werknemers, uit vrees dat de kwaliteit van het werk eronder zou kunnen lijden. In dit geval kan het gedrag van het personeel de maatregelen in de weg staan, bijvoorbeeld wanneer AC voor VR wordt gebruikt en mensen de ramen openen. De sector handel vertoont ook potentieel op het gebied van ventilatie en airconditioning (VAC) en in de levensmiddelensector kan koel- en vriesapparatuur voor VR worden gebruikt. Afhankelijk van de aard van de winkels kunnen specifieke apparaten zoals bakovens of entertainmentapparatuur het potentieel vergroten. Deze mogelijkheden zijn gedeeltelijk erkend en er wordt rekening gehouden met de mogelijkheden deze te

benutten. Het samenvoegen van mogelijkheden kan in de detailhandel eenvoudiger zijn, bijvoorbeeld wanneer meerdere winkels eigendom van hetzelfde bedrijf zijn. De besluitvorming kan ook eenvoudiger zijn wanneer alleen het hoofdkantoor moet worden overtuigd en de maatregelen in de winkels worden uitgerold. De reguliere fases van de renovatie kunnen worden gebruikt om de noodzakelijke stuursystemen te installeren. In de horecasector (hotels en restaurants) veroorzaakt keukenapparatuur, naast VAC- en koeluitrusting, hoge belastingen en kunnen deze worden gebruikt voor VR. In grote keukens bestaan deze besturingstechnologieën vaak al voor het afvoeren van de belasting, maar de keukentoestellen zijn meestal niet flexibel genoeg en moeten op verzoek klaar staan wanneer er maaltijden voor de gasten moeten worden bereid. Alle belanghebbenden zijn het eens met de algemene relevantie van de VR-opties, maar hebben bedenkingen bij de kosten of de mogelijke verstoring van arbeidsprocessen. Dit wordt met name door de belanghebbenden uit de subsectoren als een kwestie gezien, maar overschat door deskundigen en technologieleveranciers. Ook werden faciliterende factoren voor de implementatie genoemd, zoals regelmatige renovatie, aanvullende voordelen zoals een betere controle en monitoring van apparaten en de hiermee gepaard gaande synergiën met energie-efficiëntiemaatregelen. De herziening van de EPBD (Europese Commissie, 2018; Richtlijn 2018/844) versterkt de gereedheid van gebouwen voor VR en kan dus de verspreiding van deze technologieën ondersteunen. Dit heeft ook te maken met een lagere financiële inspanning voor technische uitrusting om in de toekomst VR te realiseren. Energiebeheer, technologische ontwikkelingen en veranderingen in de regelgeving kunnen worden gezien als deuropeners voor VR, vooral indien een vereenvoudigde prekwalificatie en aggregatie van mogelijkheden noodzakelijk is. De tarieven voor de gebruiksduur kunnen eveneens een optie vormen voor het omzeilen van de deelnamecriteria en belemmeringen voor flexibiliteitsmarkten. Uitgaande van een stijgend aandeel van hernieuwbare energie, veranderingen in het energiesysteem en een grotere relevantie van de flexibele vraag, kan de financiële aantrekkelijkheid toenemen.

Hoofdstuk V: Vraagrespons (demand response) in de dienstensector - theoretisch, technisch en praktisch potentieel

Na hoofdstuk IV is een diepgaander onderzoek naar de geselecteerde doelgroepen kantoren, handel en horeca gerechtvaardigd, om hun flexibiliteitspotentieel te kwantificeren. Momenteel wordt het potentieel zelden benut, slechts een klein deel van de bedrijven controleert hun flexibiliteitsmogelijkheden of implementeert VR. De resultaten bevestigen de bevindingen van de kwalitatieve studie, waarin grote bedrijven over het algemeen en restaurants en levensmiddelen voor de detailhandel in het bijzonder worden geïdentificeerd als subsectoren met een grotere belangstelling voor VR. Deze bedrijfstypen zijn ook het meest bereid om VR-maatregelen te treffen. De kwantitatieve evaluatie omvat het theoretisch potentieel (dat de energievraag van flexibele apparaten weergeeft), het technisch potentieel (rekening houdend met

technische beperkingen van apparaten om hun vraag flexibeler te maken) en het praktisch potentieel (rekening houdend met de bereidheid van bedrijven). De als flexibel te beschouwen transversale apparaten worden gevormd door uitrusting voor ventilatie, airconditioning, koeling en koeltechniek, warmtepompen, nachtopslag en elektrische waterverwarming. Over het algemeen vertonen de subsectoren levensmiddelen en horeca de grootste theoretische, technische en praktische mogelijkheden. Het grootste deel van de flexibiliteit kan worden geleverd door airconditioning en koeling (koelkasten en koelruimten). Onze aannames met betrekking tot technische beperkingen zijn zeer conservatief, uitgaand van een technisch potentieel van 1-2 uur per apparaat per dag. Het totale technische potentieel van de door ons geselecteerde sectoren bedraagt bijna 20% van het theoretisch potentieel. Alleen voor de bedrijven die zich bereid hebben verklaard om VR te implementeren, bedraagt het praktisch potentieel nog steeds ongeveer 25% van het totale technische potentieel. Verschillen tussen de apparaten voor wat betreft de bereidheid deze voor VR te gebruiken, kunnen worden verwacht: de flexibilisering van ventilatie en airconditioning is relatief zeer geaccepteerd; koelapparaten lijken minder kritisch te zijn in het gebruik dan koelapparaten. Met de opname van alle andere flexibele apparaten in de beschreven subsectoren resulteren onze schattingen in ongeveer 22 TWh theoretisch potentieel (~ 35% van het totale elektriciteitsverbruik van de subsectoren), 4 TWh technisch potentieel en 1 TWh praktisch "first mover"-potentieel. De bereidheid (d.w.z. de intentie om VR te implementeren) is afhankelijk van de omstandigheden en de bijbehorende drijvende factoren en barrières. Met name het belang van VR voor de energietransitie, de geschiktheid van toestellen voor VR, de financiële aantrekkelijkheid en het risico dat maatregelen interne processen verstoren, spelen een belangrijke rol. Zij weerspiegelen de houding, de technische eisen, de economische aantrekkelijkheid en de organisatorische geschiktheid van VR. Financiële kwesties en houding spelen een grotere rol voor kleine bedrijven, uitgaand van een koppeling met hun kleinere potentieel per bedrijf. Voor grotere bedrijven zijn vooral technische beperkingen van invloed op de bereidheid tot het implementeren van VR. Naast de algemene bereidheid is ook de prioritering van VR door het management van belang voor de besluitvorming. Hierbij spelen met name het positieve imago-effect van VR en de organisatorische inspanning van maatregelen een rol. Daarnaast verhoogt het uitvoeren van een energie-audit (d.w.z. het verzamelen van ervaringen met energiemaatregelen) de prioriteit van VR in een bedrijf.

Hoofdstuk VI: De flexibele inzet van de dienstensector - een modelleringsbenadering van de vraagrespons met gegevens uit een marktonderzoeksstudie

De focus van dit hoofdstuk ligt op de technische en praktische flexibele vraag, die daadwerkelijk kan worden ingezet. Vergeleken met de mogelijkheden die door bedrijven kunnen worden geboden, wordt bij deze benadering rekening gehouden met de vereiste flexibiliteit, waarbij de afstemming van de mogelijkheden en de behoefte aan

flexibiliteit in het elektriciteitssysteem wordt beoordeeld. De match wordt berekend door uit te gaan van de belastingscurven van de beschikbare flexibele apparaten en de restbelastingscurve, waarbij ook rekening wordt gehouden met bijvoorbeeld de opwekking uit hernieuwbare energiebronnen, de weersomstandigheden en de ontwikkeling van het energieverbruik. Bij de ramingen is uitgegaan van dezelfde verbruiksgegevens voor flexibele apparaten als in hoofdstuk V en van een scenario met een aandeel van 50% hernieuwbare energie, d.w.z. het streefcijfer voor 2030.

Indien alle geselecteerde subsectoren VR implementeren, kan een technische flexibiliteitstoepassing van 7,7 TWh worden bereikt en de grootste technische flexibiliteitsontwikkeling worden gerealiseerd in de sectoren handel (3,4 TWh) en horeca (2,6 TWh) en met de apparatuur voor ventilatie en airconditioning (VAC, 2,8 TWh) en koel- en vriesprocessen (2,6 TWh). Aangezien het technisch potentieel niet beperkt blijft tot 1 à 2 uur per dag per apparaat, maar het een gevolg is van het elektriciteitsverbruik van de verbruikers, is de berekende inzetbare flexibiliteit van de elektriciteit groter dan in hoofdstuk V werd berekend. Gezien de ontwikkelingen tot 2030 kunnen sommige mogelijkheden geringer blijken te zijn, daar het elektriciteitsverbruik van de apparaten kan afnemen. De inzetbaarheid van de flexibiliteit varieert afhankelijk van weersomstandigheden en seizoenen. Terwijl AC alleen tijdens de zomermaanden beschikbaar is, worden verwarmingsapparaten zoals nachtverwarming en warmtepompen niet gebruikt gedurende het warme zomerseizoen. De beschikbaarheid van flexibiliteit valt gedeeltelijk samen met het overschot aan hernieuwbare energiebronnen (HEB): ongeveer 20% (0,5 TWh) van het totale overschot aan HEB van 2,5 TWh zou door de betrokken sectoren kunnen worden geabsorbeerd. In een ander scenario met 80% HEB's (hetgeen in veel landen het minimumaandeel van HEB's tegen 2050 kan zijn), komt de beschikbaarheid van flexibele belastingen vaker overeen met het HEB-overschot en kan ongeveer 1,6 TWh worden geabsorbeerd door de door ons geselecteerde sectoren. Indien alleen de bedrijven die zich bereid hebben verklaard, deel te nemen aan het HEB-scenario van 50% in aanmerking worden genomen, wordt het verbruik van flexibele apparaten teruggebracht tot 16,5%. Hierdoor wordt de praktische flexibiliteit teruggebracht tot 1,8 TWh (24% van de technische flexibiliteit) en kan slechts 0,1 TWh aan HEB-overschot (26% van de technisch haalbare reductie) door de geselecteerde sectoren worden geabsorbeerd. Aangenomen mag echter worden dat de bereidheid tot het implementeren van VR kan toenemen in de periode tot 2030, indien de waarde van de flexibele vraag stijgt en technische normen en bestuurbaarheid van apparaten het gebruik van het flexibiliteitspotentieel vergemakkelijken. Ervan uitgaande dat de prijs van elektriciteit afhankelijk is van de restbelasting, kan de toekomstige realtime-elektriciteitsprijs worden berekend op basis van de restbelasting in 2030, inclusief een HEB-aandeel van 50%. Als gevolg van kleinere spreads gedurende twee opeenvolgende uren wordt de financiële waarde van een gebruikt flexibel MWh aan elektriciteit geschat op 23 euro.

Hoofdstuk VII: Hoeveel belastingsflexibiliteit kunt u met een euro kopen? Bevindingen uit een keuze-experiment met bedrijven in de Duitse handels- en dienstensector

Naast de vraagflexibiliteit in de dienstensector en de inzetbaarheid hiervan, hebben de enquêtegegevens ons in staat gesteld, meer te weten te komen over de bereidheid om vraagrespons afhankelijk van vergoedingen te accepteren. De bedrijven die zich bereid verklaarden om VR te implementeren, werden uitgenodigd om deel te nemen aan een keuze-experiment. Zij werden op willekeurige basis naar een flexibel apparaat gevraagd en of zij ermee zouden instemmen om het automatisch te sturen ten behoeve van VR, indien zij hiervoor een vergoeding zouden ontvangen. Elk bedrijf kreeg twee van deze scenario's voorgelegd, d.w.z. werd gevraagd naar twee verschillende apparaten. Het scenario varieerde in frequentie (tussen twee maal per dag en één maal per week), duur (tussen 30 en 90 minuten) en tijdsbestekken (op elk moment versus alleen op afgesproken tijdstippen) van automatische besturing. Het experiment maakt het mogelijk om indicatieve gemiddelde kosten per MWh te schatten, om het economische flexibiliteitspotentieel van de bedrijven voor uitrusting ten behoeve van ventilatie, airconditioning, koeling en vriestechniek te activeren. Veel van de bedrijven hebben het aanbod in het experiment of algemeen aanvaard, of algemeen genegeerd en de hieruit voortvloeiende betalingen zijn aanzienlijk gespreid. Aangenomen mag worden dat de bedrijven geen ervaring hebben met de markt en dus onzeker zijn over een adequate betaling en om redenen van strategie of houding de neiging hebben om al dan niet aan VR deel te nemen.

Voor ventilatie en airconditioning (VAC) bedraagt de gemiddeld verwachte vergoeding per jaar voor de deelnemende bedrijven ongeveer 1.400 euro. Voor ventilatie verwachtten de bedrijven een jaarlijkse betaling van gemiddeld 1.200 euro, voor airconditioning ongeveer 1.700 euro per jaar. Er werd geen effect van duur en frequentie vastgesteld, maar indien de flexibiliteit alleen binnen de afgesproken termijnen wordt gevraagd, worden de verwachte vergoedingen verlaagd (met ongeveer 1/3). Wanneer men ventilatie en airconditioning vergelijkt, biedt airconditioning een groter en kosteneffectiever potentieel. Het potentieel is hoger, maar de verwachte betaling verschilt niet veel van die voor flexibele ventilatie. Rekening houdend met het gemiddelde elektriciteitsverbruik (technisch potentieel) van AC van bedrijven die aan het experiment deelnemen, zou het potentieel van de ventilatietoestellen kunnen worden gemobiliseerd met ongeveer 800 €/MWh en zou het potentieel voor airconditioning kunnen worden vrijgemaakt met ongeveer 300 €/MWh (uitgaand van een flexibel aandeel van 4% van het elektriciteitsverbruik voor ventilatie en 11% voor airconditioning). Voor koeling en vriestechniek bedragen de gemiddeld verwachte jaarlijkse vergoedingen ongeveer 2500 euro, terwijl de betaling voor een flexibele vraag naar het gebruik van vriestechniek in vergelijking met koelapparatuur aanzienlijk hoger moet zijn. Indien deze cijfers in verhouding tot het elektriciteitsverbruik worden gebracht, zou het potentieel van koeling/vriezen kunnen worden gemobiliseerd voor

gemiddeld ongeveer 900 €/ MWh. De frequentie, de duur en de tijdsbestekken hadden geen effect op deze cijfers, grotere bedrijven hebben echter in totaal meer subsidies nodig.

Hoofdstuk VIII: Energie-efficiëntie en vraagrespons - twee kanten van dezelfde medaille?

Een duurzaam energiesysteem dient energie-efficiëntie en flexibiliteit te omvatten. Daarom is het van belang om manieren te vinden om beide concepten in synergie te bevorderen. Vanuit het perspectief van bedrijven zijn beide concepten met elkaar verwant, omdat zij gericht zijn op het beïnvloeden van hun energieverbruik, maar voor wat de praktische implementatie betreft, stellen zij hen voor verschillende uitdagingen. In alle subsectoren komen energie-efficiëntiemaatregelen veel vaker voor (in ongeveer 50% van de bedrijven in de dienstensector) dan maatregelen die gericht zijn op de vraag (minder dan 10%) en het aandeel is het grootst voor grote bedrijven en in de subsectoren van de horeca. Energie-efficiëntiemaatregelen (EE) worden geïmplementeerd voor alle sectoroverschrijdende apparatuur en richten zich meestal op verlichting en sensoren, verwarming en IT/energiebeheer. 17% van de bedrijven die EE-maatregelen hebben geïmplementeerd, verklaarde dat ten minste één van de maatregelen door de Duitse federale regering of door incentieven van de deelstaten (Bundesländer) werd gesubsidieerd of gefinancierd. Maatregelen om in te spelen op de vraag (VR) worden gewoonlijk gebruikt voor interne optimalisatie van de vraag, zoals het afbouwen van de belasting of de optimale inkoop van elektriciteit. Slechts 1% van de onderzochte bedrijven verklaarde dat zij op de balanceringsmarkten actief zijn. Bepaalde factoren beïnvloeden en ondersteunen de implementatie van energiegerelateerde maatregelen (bv. audits, energiebeheersystemen of systemen voor gebouwenbeheer, etc.) De bedrijven die zowel EE- als VR-maatregelen toepassen, zijn ook de bedrijven die gebruik maken van bouw- of energiemanagementsystemen en audits uitvoeren. Uit de analyse is gebleken dat de meeste van deze factoren een positieve invloed hebben op de waarschijnlijkheid, dat beide maatregelen worden uitgevoerd. Toch zijn bedrijfskenmerken zoals sector en omvang relevanter voor het uitvoeren van VR-maatregelen dan voor EE, hetgeen erop wijst dat VR beter geschikt is voor bepaalde soorten bedrijven, terwijl EE minder specifiek is. Energie-efficiëntiemaatregelen vereisen doorgaans een verandering in de richting van efficiëntere apparaten of modernere systemen, terwijl VR-maatregelen een verandering in individuele normen of routines kunnen inhouden, bijvoorbeeld wanneer tarieven worden gewijzigd of contracten met dienstverleners moeten worden gesloten. De relevante factoren en de drijvende krachten met de grootste invloed c.q. belemmeringen zijn dezelfde voor VR en EE, maar VR-maatregelen zijn minder gebruikelijk en beginnen op een ander niveau dan voor EE het geval is. Beide soorten maatregelen kunnen worden beschouwd als maatregelen die de vraag naar energie beïnvloeden en worden door bedrijven niet volledig anders ervaren. Dit wijst erop dat instrumenten die met

succes energie-efficiëntiemaatregelen bevorderen, ook zouden kunnen werken voor het stimuleren van de vraag naar energie.

Er is onderzocht of aspecten van de flexibiliteit van de vraag naar energie kunnen worden overgedragen op of geïntegreerd in de bestaande soorten beleidsinstrumenten voor energie-efficiëntie. Sommige instrumenten ondersteunen reeds impliciet maatregelen om op de vraag te reageren, zoals incentieven om energiebeheersystemen of richtlijnen ter bevordering van de "intelligentie" van een gebouw toe te passen, met het oog op een efficiënte en comfortabele werking van het gebouw, de mogelijkheid het aan te sluiten voor het opladen van elektrische voertuigen en de ondersteuning van de vraagrespons in een gemoderniseerde elektriciteitsmarkt. Andere instrumenten kunnen in principe ook worden toegepast voor de bevordering van VR, zoals auditverplichtingen en andere informatie-instrumenten (bv. energie-efficiëntienetwerken), idealiter in combinatie met financiële steun voor de vastgestelde maatregelen. Standaardiseringsmaatregelen zouden ook kunnen beginnen bij apparaten, met een norm voor apparaten die “VR-gereed” zijn, die vergelijkbaar is met efficiëntienormen. Door het minder ontwikkelde regelgevingskader en de sterkere specificiteit van VR-maatregelen ten aanzien van bedrijfstypen, is het mogelijk dat voor succesvolle maatregelen nog meer maatwerk nodig is dan voor EE-maatregelen. Voor bedrijven die overwegen, VR te implementeren, is de waarde van de flexibele vraag meer afhankelijk van het aanbod en de regelgeving op de markt, de weersomstandigheden en de behoefte aan flexibiliteit dan voor energie-efficiëntie het geval is. Desalniettemin kunnen de ervaringen met EE een rol spelen bij de implementatie van andere energiegerelateerde maatregelen en profiteren van synergiën, bijvoorbeeld door gebruikmaking van reeds beschikbare energiebeheersystemen.

2.2 Antwoorden op de onderzoeksvragen

In de volgende paragrafen worden de resultaten van de afzonderlijke hoofdstukken samengebracht en samengevat, om een antwoord op de onderzoeksvragen te bieden.

1. *Hoe kunnen energie-efficiëntiemaatregelen met succes worden geïmplementeerd bij bedrijven en welke determinanten moeten in aanmerking worden genomen?*

Het voorstellen van rendabele maatregelen en het ondersteunen van bedrijven tijdens alle fasen van de besluitvorming en de implementatie van maatregelen is gunstig gebleken voor een succesvol proces voor het verbeteren van EE. Op deze wijze kunnen de meeste relevante belemmeringen en verwachtingen met betrekking tot motivatie, winstgevendheid en informatie worden aangepakt. Deze ondersteuning stelt bedrijven in staat, verschillende uitdagingen aan te gaan, die zich in verschillende stadia van het proces voordoen. Het delen

van ervaringen en vergelijkingen met andere bedrijven verhoogt de motivatie en biedt oriëntatie. Belemmeringen zijn ook specifiek voor maatregelen en bedrijfskenmerken, met name voor de grootte en sector, die de energie-intensiteit en beschikbaarheid van technologieën en faciliteiten bepalen. Daarnaast spelen factoren zoals de autonomie van de onderneming, de relatie met klanten en besluitvormingsprocessen een rol. Een goede implementatieprocedure houdt rekening met deze noodzakelijke match en de specifieke behoeften van de bedrijven. De belangrijkste categorieën barrières die in de literatuur worden aangetroffen, namelijk technische, organisatorische, economische, gedrags- en externe barrières, kunnen worden bevestigd, terwijl barrières die verband houden met tijd en geld vaak het hoogst worden geprioriteerd. Om de risico's van vroegtijdige mislukking te beperken indien maatregelen worden verwaarloosd, omdat ten onrechte wordt aangenomen dat zij niet rendabel zouden zijn, moet het mogelijk zijn om met slechts een geringe inspanning geschikte en rendabele maatregelen te identificeren.

Algemene succesfactoren omvatten:

- Gemakkelijk beschikbare informatie en ondersteuning tijdens alle stadia van de besluitvorming en implementatie, omdat elk stadium verschillende barrières en uitdagingen omvat;
- Er moet rekening worden gehouden met de structurele kenmerken van de onderneming en met economische, technische, gedrags- en motiverende en externe/informatiegerelateerde belemmeringen;
- De implementatie van maatregelen kan worden gefaciliteerd middels de volgende benaderingen:
    - de drempels voor energiegerelateerde maatregelen moeten worden verlaagd: audits, energiemanagementsystemen en de installatie van besturingstechnologieën voor energieverbruikende apparaten kunnen als deuropeners dienen;
    - wanneer een leidinggevende in een bedrijf verantwoordelijk is voor energievraagstukken en wanneer beslissingen over energiemaatregelen intern kunnen worden genomen, verloopt het besluitvormings- en implementatieproces meestal vlotter;
    - bij de besluitvorming kunnen ongunstige rentabiliteitsbenchmarks, zoals korte terugverdienperiodes, maatregelen in de weg staan; er moet ook rekening worden gehouden met langetermijnvoordelen en niet-energievoordelen om de waarde van de maatregelen te verhogen;
    - de inspanning moet laag worden gehouden voor de onderneming:

- invoeren van een zelfbeoordelingsinstrument voor de eerste screening van mogelijke maatregelen, die aansluiten bij de verwachtingen en kenmerken van de onderneming;
- diensten of one-stop-solutions voor de identificatie en implementatie van maatregelen.

2. *Welke bedrijven vormen doelgroepen voor vraagflexibiliteit in de dienstensector en hoe groot is hun potentieel?*

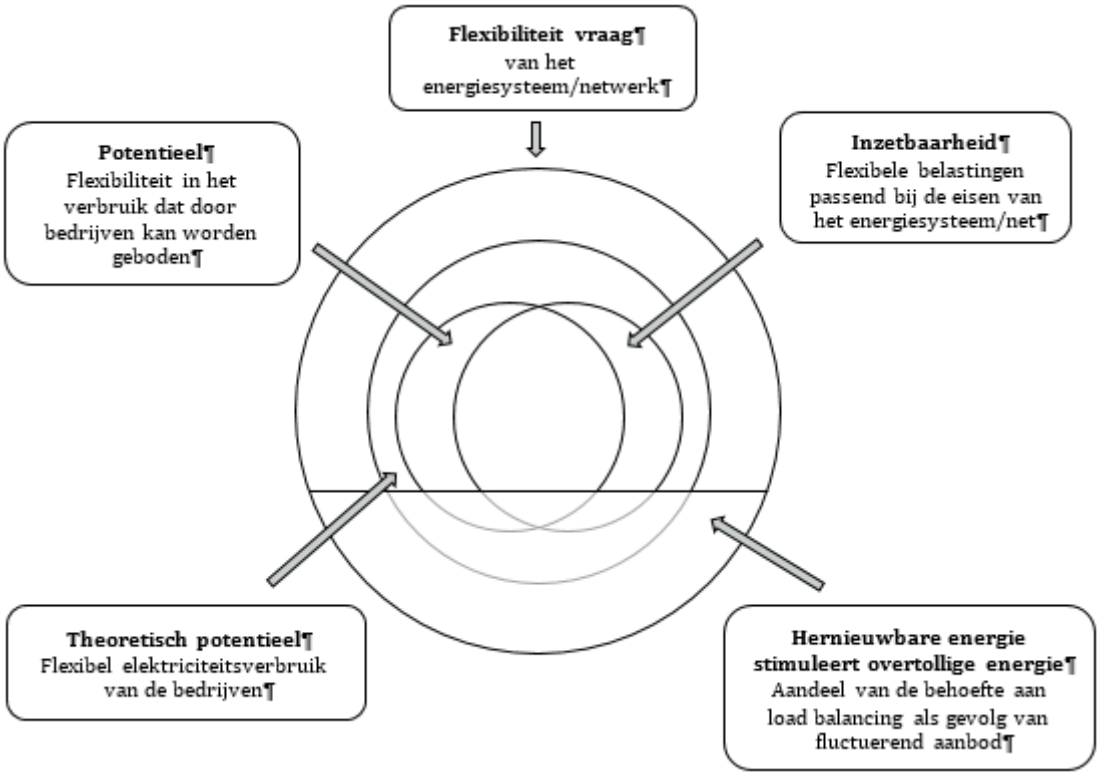
Op dit moment blijft het potentieel in de dienstensector nog grotendeels onbenut, in tegenstelling tot in de industriële sector. Naast de energie-intensieve bedrijven met flexibele energieverbruikende apparaten die niet tot de kernactiviteit behoren (en dus minder kritisch zijn wanneer zij voor VR-doeleinden worden gebruikt), kunnen zij voor VR van bijzonder belang zijn. Door de homogene verdeling van de dienstverleners over het land kan hun potentieel een aanvulling vormen op regionaal gerichte VR in de industriesector. Aangezien de dienstensector ongeveer 30% van de Duitse elektriciteitsvraag voor zijn rekening neemt, zou deze een belangrijke rol kunnen spelen voor VR en zelfs nog belangrijker kunnen worden gezien de voortdurende ontwikkeling naar een diensteneconomie. De eerste stap voor het identificeren van de doelgroepen in de dienstensector bestond uit het selecteren van de subsectoren met het grootste aandeel in het elektriciteitsverbruik, met name die subsectoren waar flexibele apparaten een groot deel van dit verbruik genereren. De subsectoren kantoren, handel en horeca (hotels en restaurants) zijn samen goed voor meer dan 50% van het totale elektriciteitsverbruik van de gehele sector. De detailhandel en groothandel in levensmiddelen en hotels vertonen het hoogste elektriciteitsverbruik per onderneming, terwijl kantoren een groot aandeel hebben in het totale elektriciteitsverbruik, maar het kleinste verbruik per onderneming in vergelijking met de andere subsectoren. Apparaten met een flexibel verbruik worden benut voor ventilatie, airconditioning, koeling en bevriezing, alsmede uitrusting voor elektrische waterverwarming, nachtverwarming, en warmtepompen.

Bij het inschatten van het flexibiliteitspotentieel werden verschillende analytische dimensies in aanmerking genomen, waarbij het theoretische, technische, economische en praktische potentieel werd gedefinieerd. De beschikbaarheid van flexibele apparaten bepaalt het flexibele energieverbruik, d.w.z. het theoretisch potentieel; de technische beperkingen voor het flexibeler maken van de vraag beïnvloeden het technisch potentieel. Deze technische beperkingen komen bijvoorbeeld tot uiting in de duur en de frequentie waarmee apparaten flexibel kunnen worden gebruikt ten behoeve van VR, zonder dat dit een negatief effect heeft op de productiviteit. Het praktisch potentieel wordt bepaald door de bereidheid om VR in te zetten. Naast het potentieel dat de beschikbare flexibele vraag vertegenwoordigt, wordt ook rekening gehouden met de inzetbaarheid van dit potentieel, d.w.z. het tijdstip en de afstemming van de beschikbaarheid en de behoefte aan flexibiliteit.

De resultaten vloeien voort uit het optimalisatiemodel (uitgaande van een aandeel van 50% hernieuwbare energie, gebruikmakend van productie- en verbruiksprofielen). Afbeelding IX-1 geeft de relatie weer tussen de begrippen vraag naar flexibiliteit, potentieel en inzetbaarheid.

Afbeelding IX-1: Illustratie van de flexibiliteit vraag, het potentieel en de inzetbaarheid

De afgebeelde grootes van de concepten hebben geen betrekking op realistische verhoudingen.



Restaurants en handels (food)-sectoren vertonen het hoogste elektriciteitsverbruik voor wat betreft flexibele apparaten en vertegenwoordigen dus het hoogste theoretische potentieel. Voor de betrokken sectoren zorgt met name de flexibele apparatuur voor airconditioning en koeling (koelkasten en koelruimten) voor de hoogste elektriciteitsvraag. Er zij op gewezen dat de apparaten ook verschillen in de wijze waarop zij voor verschillende doeleinden kunnen worden gebruikt; zo hebben zowel AC- als koelprocessen een hoog VR-potentieel, maar wordt AC binnen vooraf bepaalde periodes gebruikt en wordt koeling continu gebruikt. AC bleek vanwege het belastingsprofiel het best te voldoen aan de eisen voor integratie van duurzame energiebronnen, maar de behoefte aan AC binnen specifieke tijdsbestekken maakt het gevoeliger wanneer de automatische inzet van flexibiliteit wordt uitgevoerd zonder vooraf bepaalde tijdsbestekken te gebruiken. Koeling kan gemakkelijker automatisch worden geregeld, maar het proces is over het algemeen kritischer dan dat voor AC.

De resultaten van onze schattingen zijn te vinden in tabel IX-2. Het theoretisch potentieel is het totale verbruik van flexibele apparaten in de genoemde sectoren en is goed voor ongeveer 35% van het totale elektriciteitsverbruik in de subsectoren. Het technisch potentieel varieert in functie van de veronderstellingen m.b.t. de mate waarin de toestellen flexibel kunnen worden ingezet (scenario's A en B). De technische inzetbaarheid ligt dichter bij scenario B, d.w.z. de aanvaarding van een intensiever gebruik van de toestellen voor VR-doeleinden vormt een sterkere beperking van de inzetbaarheid van de flexibiliteit dan de behoefte aan flexibiliteit van de vraag. De flexibiliteit die kan worden gebruikt om de restbelasting af te vlakken, wordt geschat op 0,5 TWh. Het praktisch potentieel en de praktische inzetbaarheid houden alleen rekening met de bedrijven die bereid zijn, VR te implementeren.

Het economisch potentieel is moeilijk in te schatten omdat er momenteel weinig opties bestaan voor de dienstensector voor het verhandelen van zijn flexibele vraag. Toekomstige ontwikkelingen wijzen op een waardestijging, maar de marketingmogelijkheden moeten nog verder worden ontwikkeld. Modellering van prijssignalen als marktconforme incentieven leidt tot een mogelijke winst van 23 €/MWh. De in het model opgenomen invoering van flexibiliteit is marktconform en wordt ondersteund door gemodelleerde prijssignalen uit een spotmarkt. Andere (voornamelijk op het net gebaseerde) stimuleringssystemen en mogelijke toekomstige incentieven voor flexibel gedrag, zoals variabele netwerktarieven, kunnen hogere potentiële inkomsten opleveren. De inkomsten op de balanceringsmarkten bedragen momenteel ongeveer 400 - 700 €/MWh, maar zijn nog niet toegankelijk voor de dienstensector. De door de bedrijven verwachte vergoedingen zijn afhankelijk van de details van de procedure voor het flexibeler maken van de apparaten en hun eigenschappen, maar kunnen worden geraamd op een vergelijkbaar niveau van ongeveer 300 tot 900 €/ MWh.

Table IX-2: Samenvatting van het flexibiliteitspotentieel en de invoering ervan

		Eenheid	VAC	RF	HW	HP	NSH	Toteal
Potentieel ("beschikbare" flexibiliteit	Theoretisch potentieel (elektriciteitsverbruik)	TWh	7.83	9.27	2.90	0.30	1.79	22.09
	Technisch potentieel Scenario A	TWh	0.45	1.20	0.36	0.02	1.79	3.82
	Technisch potentieel Scenario B	TWh	1.6	2.4	0.36	0.04	1.79	6.19
	Praktisch potentieel (A)	TWh	0.14	0.43	0.08	<0.01	0.29	0.90
Inzetbaarheid ("vereiste" flexibiliteit)	Technische flexibiliteits-implementatie	TWh	2.75	2.64	1.22	0.13	0.99	7.74
	Praktische flexibiliteits-implementatie	TWh	0.65	0.64	0.30	0.03	0.20	1.82
	Technische) reductie van HEB-overschot aan elektriciteit	TWh	0.18	0.14	0.01	0.07	0.10	0.51
	Verwachte economische inkomsten	€/MWh	800/ 300	900	n/a	n/a	n/a	n/a

VAC: Ventilatie & Airconditioning, RF: Koeling, HW: Warm Water, HP: Warmtepompen, NSH: Nachtopslagverwarming
Scenario A: 1-2 uur flexibel gebruik per apparaat per dag, scenario B: verdubbeld flexibel gebruik (voor details cp. hoofdstuk V).
De cijfers zijn gedeeltelijk afgeleid van de oorspronkelijke gegevens en worden niet in dezelfde mate in de documenten gepresenteerd.

3. Welke bepalende factoren beïnvloeden dit flexibiliteitspotentieel in bedrijven in de dienstensector?

Zoals eerder in de inleiding werd uitgelegd, vormen met name technische, organisatorische, economische, gedrags- en externe determinanten het kader voor de analytische dimensies voor beoordeling van de factoren die van invloed zijn op de vaststelling van energiegerelateerde maatregelen. De dimensies zijn gedeeltelijk aan elkaar gekoppeld, en elk van deze dimensies kan bestaan uit belemmerende of ondersteunende aspecten, die het potentieel van bedrijven om maatregelen te implementeren beïnvloeden (cp. afbeelding IX-2). Controle over deze factoren opent de mogelijkheid tot het gebruikmaken van de drijvende krachten en het reduceren van de barrières, om het VR-potentieel volledig te kunnen benutten.

De volgende aspecten werden relevant geacht om de vraag bij bedrijven flexibel(er) te maken:

- **Gedragsdimensie** - houding en motivatie van betrokken personen die het gedrag beïnvloeden
    - Positieve houding ten opzichte van maatregelen: de overtuiging dat de maatregelen een belangrijke bijdrage leveren aan de energietransitie bleek een belangrijke drijfveer te zijn voor het treffen van energiegerelateerde maatregelen.
    - Positieve imago-effecten voor de klant: vooral in sectoren waar men een nauwe relatie met de klant heeft, kan het genereren van een positief imago een verkoopargument voor energiegerelateerde maatregelen vormen, die het bedrijf kunnen onderscheiden van de concurrentie.
    - Prioritering van energievraagstukken/management is overtuigd: dit aspect vormt vaak een voorwaarde voor het hanteren van mogelijke maatregelen. De prioritering is hoger wanneer energiemaatregelen als strategisch worden ervaren en is meestal laag wanneer de energiekosten laag zijn en er een klein potentieel wordt verwacht.
    - Comfort: de maatregelen mogen geen afbreuk doen aan het comfort van werknemers of klanten, aangezien de kwaliteit van het werk of de dienst(en) er onder kan lijden. Dit aspect hangt nauw samen met de organisatorische dimensie, zoals werkprocessen, werktijden en de werking van flexibele apparaten.

- **Technische dimensie** - beschikbare flexibele apparaten, beperkingen met betrekking tot hun werking en ondersteunende technologieën
    - Geschiktheid: de beschikbaarheid van apparaten die flexibel inzetbaar zijn. Dit aspect heeft betrekking op organisatorische aspecten, het bepalen van de beschikbaarheid van sector- en groottespecifieke apparaten en de specifieke kenmerken van hun werking.
    - Kenmerken van het apparaat: deze kenmerken zijn van invloed op de bereidheid van bedrijven om het specifieke apparaat voor VR te gebruiken, bijvoorbeeld wanneer het gebruik van het apparaat een continu bedrijf vereist of wanneer het apparaat gevoelig is voor in- en uitschakelen. Daarom is het gebruik van VR voor AC doorgaans meer geaccepteerd dan voor vriesapparatuur. Aan de andere kant vormt de werking van AC geen continu proces, d.w.z. het is gevoeliger voor interferentie, omdat het alleen nodig is binnen vooraf bepaalde tijdsbestekken. Indien de flexibele werking van een dergelijk apparaat niet kan worden voorspeld of beïnvloed, wordt het gebruik ervan voor VR-doeleinden minder geaccepteerd. De normale werking van een apparaat bepaalt ook de mogelijke waarde van diens flexibiliteit, bijvoorbeeld of het apparaat flexibel beschikbaar is wanneer er flexibiliteit in het systeem wordt benodigd.
    - Energiebeheersystemen/gebouwenbeheer- of besturingsapparatuur: deze ondersteunende technologieën vergemakkelijken de identificatie van maatregelen, de besturing van apparaten en de initiële kosten en inspanningen.

- **Organisatorische dimensie** - interne processen, verantwoordelijkheden en werkprocessen
    - Kenmerken van het bedrijf: grootte en sector van een bedrijf bepalen de energie-intensiteit, de kernactiviteit, de beschikbare toestellen en de vraag of er personen verantwoordelijk zijn voor de energieproblematiek.
    - Besluitvormingsprocessen: een energiemanager die de verantwoordelijkheid op zich neemt om energiegerelateerde maatregelen te stimuleren, bevordert in de meeste gevallen de implementatie ervan. Wanneer het bedrijf niet bevoegd is om zelf beslissingen te nemen (bijvoorbeeld omdat het deel uitmaakt van een concern of niet de eigenaar van de apparaten is), kan de implementatie van maatregelen worden belemmerd. In het geval van ketens kan centrale besluitvorming de uitrolling vergemakkelijken en versnellen, hetgeen vooral interessant kan zijn voor het bundelen van de lasten voor VR en het verlagen van de transactiekosten.
    - Werkprocessen: het flexibel inzetten van apparaten draagt het risico van procesverstoringen met zich. Deze barrière wordt in de dienstensector lager geprioriteerd dan bij industriële bedrijven, omdat flexibele apparaten meestal niet tot de kernactiviteit behoren. Toch kan de werking van apparaten in wisselwerking staan met werkprocessen of gewoonten van werknemers/klanten.
    - Inspanningen: een hoge organisatorische inspanning vermindert meestal de intentie tot het treffen van maatregelen en gaat gepaard met kosten. De inspanning die nodig is voor het gebruik maken van het flexibele potentieel van een bedrijf heeft een wisselwerking met technische (bv. beschikbaarheid van besturingstechnieken), organisatorische (personen die verantwoordelijk zijn voor energievraagstukken) en motiverende (bv. de bereidheid en prioritering) aspecten.
    - Energie-intensiteit/verbruik: bij bedrijven met een lage energie-intensiteit is het aandeel van de energiekosten meestal klein en de relevantie van de energieproblematiek laag. Dit aspect heeft een wisselwerking met de motiverende aspecten voor het implementeren van maatregelen.
    - Ervaring: ervaringen met andere energiegerelateerde maatregelen kunnen de kennis over het energieverbruik vergroten en de identificatie van de mogelijkheden en een competente selectie van maatregelen vergemakkelijken.

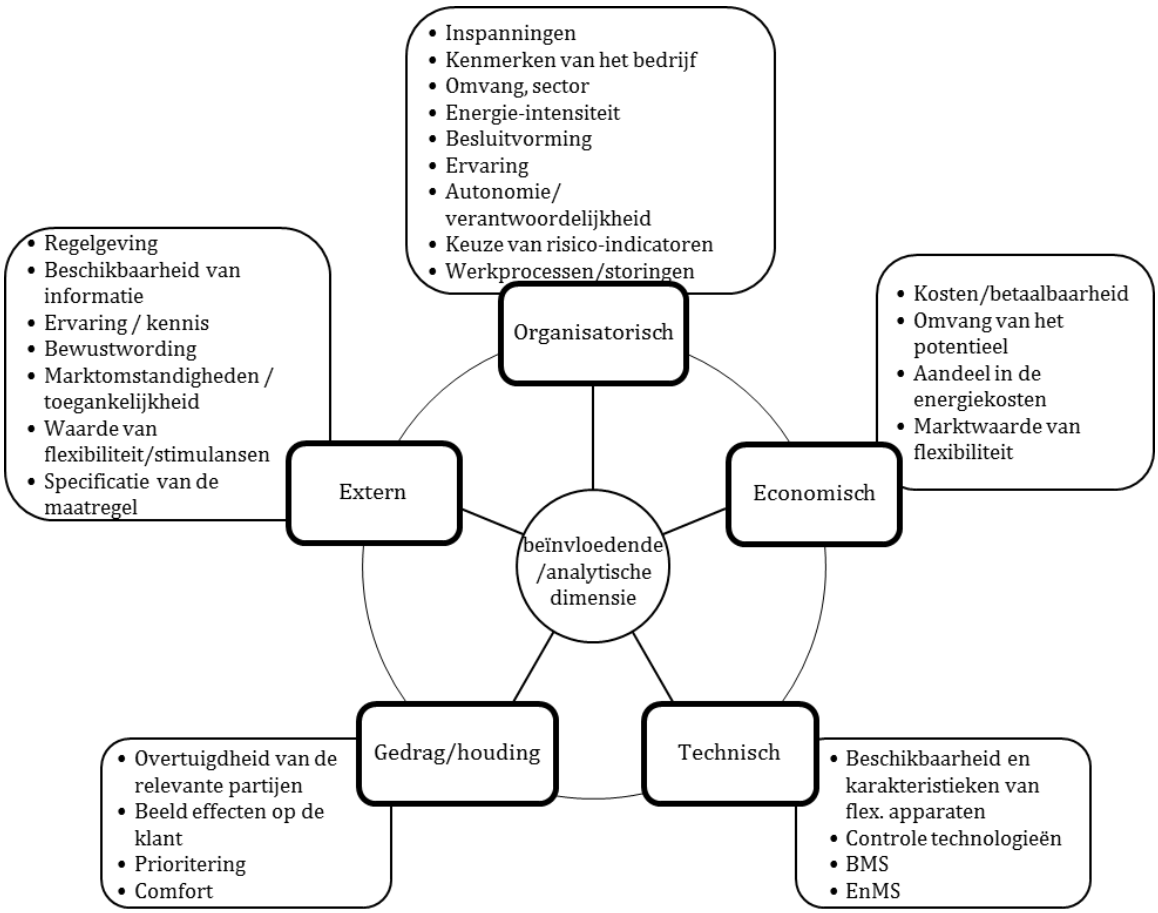
- **Economische dimensie** - financiële aspecten met betrekking tot winstgevendheid en kosten
    - Winstgevendheid: winstgevendheid is niet onafhankelijk van randvoorwaarden (bv. regulering en markttoegang). De winstgevendheid wordt beïnvloed door de volgende potentiële factoren:
    - maatregelen/noodzakelijke apparaten zijn te duur of niet betaalbaar,
    - energiekosten,

- slechte beoordeling van de winstgevendheid,
- verwachte winst in verhouding tot de inspanningen/risico's ,
- geringe waarde van flexibiliteit/gebrek aan (regelgevende) incentieven (bv. wanneer een constant verbruik beter wordt beloond).

- **Externe dimensie** - omstandigheden, regelgeving en marktomstandigheden
  - Regulering: indien het regelgevingskader onduidelijk is of zelfs de deelname aan de markten belemmert en bemoeilijkt, zal geen rekening worden gehouden met VR. Een niet-stimulerende regulering verlaagt ook de rentabiliteit van de maatregelen.
  - Markttoegang: deelname aan de balanceringsmarkt is ingewikkeld of nauwelijks mogelijk, met name voor kleine energiegebruikers.
  - Informatie: de beschikbaarheid van informatie wordt beïnvloed door de ontwikkelingsfase van de markt en de standaardisering van processen of de toegankelijkheid van markten, vooral wanneer de toewijzing van informatie veel moeite kost en er weinig ervaring bestaat. In tegenstelling tot energie-efficiëntie-audits bestaat er geen vergelijkbare informatie over de flexibiliteitsmogelijkheden voor bedrijven.
  - Bewustwording: bewustwording hangt nauw samen met de beschikbaarheid van informatie en de motivatie en ervaring van een bedrijf op het gebied van energievraagstukken. VR is niet gebruikelijk in de dienstensector en bijna 50% van de bedrijven heeft er nog niet van gehoord. Dit maakt het moeilijker om het potentieel aan te boren.
  - Specificaties van de maatregel: specificaties beïnvloeden de acceptatie van het flexibel maken van de vraag en hebben betrekking op het apparaat en de bedrijfskenmerken, maar vormen ook onderdeel van het contract met een dienstverlener. Wanneer de werking van een apparaat voor VR-doeleinden bijvoorbeeld geen noemenswaardig effect heeft of voorspelbaar is, is de kans groter dat een bedrijf de maatregel omzet.

Uit de resultaten blijkt dat de verschillende stadia van de besluitvorming van invloed zijn op de relevantie en de rangschikking van de belemmeringen. Met name technische en economische aspecten en effecten op de werkprocessen zijn relevant voor de praktische implementatie, terwijl gedrags- en organisatorische aspecten van invloed zijn op de prioriteitstelling voor VR, d.w.z. of de onderneming geïnteresseerd is in het omzetten van de maatregelen.

Afbeelding IX-2: Beïnvloedende factoren van maatregelen ter bevordering van de energieflexibiliteit (VR)



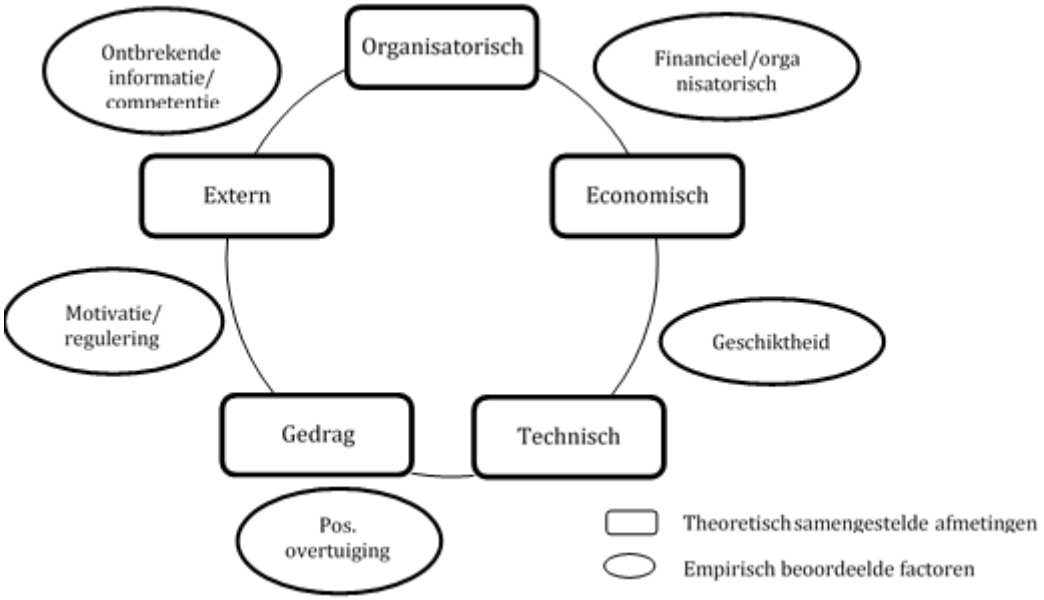
4. Hoe kunnen wij synergiën tussen flexibiliteit van de vraag en energie-efficiëntie benutten?

Zowel energie-efficiëntie als flexibiliteit van de vraag dragen bij aan de belangrijkste pijlers van de energietransitie en hebben dus hetzelfde doel. Ook vanuit het perspectief van bedrijven bestaat er een relatie - beide vereisen een verandering in het verbruikspatroon. Terwijl energie-efficiëntie een vermindering van het verbruik of een verhoging van de productiviteit betekent, betekent flexibiliteit van de vraag een verandering van het verbruikspatroon door een verlaging of verhoging van het verbruik, die afhankelijk is van de elektriciteitsopwekking of -volatiliteit. In specifieke gevallen kunnen de concepten elkaar dus tegenwerken, bijvoorbeeld wanneer het verbruik tot een minimum wordt beperkt, wordt ook het flexibiliteitspotentieel verminderd. Wanneer processen zo efficiënt mogelijk verlopen, kan het flexibeler maken van de vraag de efficiëntie verminderen. Welk concept gunstiger is met betrekking tot de efficiëntie van het energiesysteem is afhankelijk

van de situatie op het gebied van energieopwekking en netwerkstabiliteit, bijvoorbeeld in het geval van een overschot aan hernieuwbare energiebronnen of het verschuiven van de vraag naar bepaalde tijdstippen, is dit meer waard dan energiebesparingen en in het geval van instabiliteit van het net kan het niet-gebruiken van de beschikbare energie zelfs gunstig zijn. De waarde van energie-efficiëntie en/of vraagflexibiliteit hangt bijgevolg af van tijdstippen. Terwijl energiebesparing of -efficiëntie loont door kostenreductie, moet de vraagflexibiliteit extern worden gestimuleerd. Desalniettemin is het gunstig om bedrijven in staat te stellen, beide te implementeren.

De veronderstelling dat EE en VR met vergelijkbare drijvende krachten en belemmeringen te maken hebben, kan worden bevestigd, zij het met verschillen in details. Vergeleken met de algemene taxonomie liggen de empirisch beoordeelde factoren (cp. hoofdstuk VIII) diagonaal ten opzichte van de theoretisch samengestelde factoren (cp. hoofdstuk I), die de onderlinge relatie tussen de dimensies weerspiegelen. Zij leggen echter dezelfde nadruk en sommige van deze factoren hebben ook een vergelijkbare invloed op de bepaling van maatregelen (afbeelding IX-3).

Afbeelding IX-3: Empirische bevestiging van de analytische dimensies van energiegerelateerde maatregelen



Het is dan ook niet meer dan logisch dat ervaringen met EE worden gebruikt voor het bevorderen van VR, vooral omdat het flexibiliteitspotentieel tot nu toe zelden wordt benut en het beleid en de regelgeving relatief onderontwikkeld zijn. Sommige succesvolle beleidsinstrumenten kunnen worden uitgebreid of overgedragen om ook op VR toe te worden gepast. Energie-efficiëntie-audits (informatiebeleidsinstrument) bleken bijvoorbeeld een aanzienlijke invloed te hebben op de goedkeuring van energie-

efficiëntiemaatregelen. Wanneer in de audits een evaluatie van het flexibiliteitspotentieel werd opgenomen, zou ook VR kunnen worden ondersteund. Hetzelfde geldt voor energie-efficiëntienetwerken (beleidsinstrument voor onderwijs en opleiding) die ook als VR-netwerken zouden kunnen fungeren, eventueel met de mogelijkheid om binnen de netwerken partners te vinden voor het bundelen van de lasten. Fondsen of subsidies (financiële beleidsinstrumenten) kunnen bijdragen tot het wegnemen van de barrière die wordt gevormd door de investeringskosten voor noodzakelijke technologieën, zoals bijvoorbeeld systemen voor energie- of gebouwenbeheer. Deze aanvullende technologieën verhogen ook de intelligentie-indicator van het gebouw (zie EPBD) en kunnen worden bevorderd met beoordelingsnormen voor intelligente technologieën (informatie-regelgeving). Het gebruik van een label om de zichtbaarheid van de maatregelen te vergroten kan ook de imago-effecten verbeteren en als drijvende kracht fungeren. Een meer gedetailleerde evaluatie van overdraagbare beleidsmaatregelen is te vinden in hoofdstuk VIII. De algemene regelgevingsinstrumenten met betrekking tot de marketingopties van vraagflexibiliteit en markttoegang dienen nog steeds te worden verbeterd en moeten in wisselwerking staan met een hervorming van de markten, bv. door middel van de introductie van nieuwe spelers en dienstverleners. Om een begin te maken met de uitrolling van de benutting van het VR-potentieel, spelen vergelijkbare doelgroepen een rol als voor EE - bedrijven met een hoog energieverbruik en reeds beschikbare aanvullende besturingstechnologieën, die goed op de hoogte zijn van hun energieverbruik en de bedrijfstijden van hun apparaten. Zo kan EE als een enabler voor VR dienen.

2.3 Conclusies en aanbevelingen

Dit proefschrift onderzoekt succesvolle strategieën voor de implementatie van energiegerelateerde maatregelen (energie-efficiëntie en flexibiliteit van vraag), waarbij wordt gekeken naar dimensies die van invloed zijn op de mogelijkheden tot het treffen van dergelijke maatregelen. Een identificatie van de doelgroepen en een brede en gedetailleerde evaluatie van de theoretische, technische, economische en praktische mogelijkheden van vraagflexibiliteit in de dienstensector wordt gepresenteerd. De op deze resultaten gebaseerde beleidsaanbevelingen worden gebruikt voor de verbetering van de energie-efficiëntie en de flexibiliteit van de vraag.

2.3.1 Conclusies

Beïnvloedende factoren

Gedurende alle fasen van de besluitvorming, vanaf de bepaling van geschikte maatregelen tot aan de praktische implementatie ervan, moeten verschillende dimensies in aanmerking worden genomen om de factoren te identificeren, die bepalend zijn voor de succesvolle invoering van maatregelen. De taxonomie van de belemmeringen voor energie-efficiëntie werd in deze dissertatie bevestigd en met succes toegepast op de vraagrespons. Daarnaast werden houdingsaspecten van significante invloed, die de bestaande dimensies van de taxonomie kunnen aanvullen, geïdentificeerd en wordt een nieuwe en algemenere taxonomie voor energiegerelateerde maatregelen voorgesteld.

Uit de beoordeling van de prioritering van de factoren, die van invloed zijn op de intentie tot het treffen van maatregelen, en de effecten hiervan op de intentie tot het omzetten van maatregelen, is gebleken dat onderscheid moet worden gemaakt tussen barrières met een hoge waardering (die het bestaan ervan aangeeft) en de relevantie van beïnvloedende factoren (die de sterkte van het effect ervan op de intentie tot of de implementatie van maatregelen aangeeft). De geïdentificeerde analytische dimensies hebben betrekking op de belangrijke beïnvloedende factoren voor energiegerelateerde maatregelen bij bedrijven. Het potentieel van energiegerelateerde maatregelen bleek gevoelig te zijn voor de beïnvloedende factoren en ook de relevantie ervan bleek in specifieke gevallen te verschillen, bijvoorbeeld afhankelijk van het type bedrijf, het soort maatregel/gerelateerde technologie, de fase van besluitvorming. Deze bevindingen helpen om maatregelen en doelgroepen beter op elkaar af te stemmen en ondersteunende instrumenten voor een succesvolle implementatie te ontwikkelen.

Potentieel

Er moeten verschillende soorten mogelijkheden worden onderscheiden. In dit proefschrift worden de theoretische, technische en praktische mogelijkheden op het niveau van de subsectoren binnen de dienstensector en voor sectoroverschrijdende apparaten gepresenteerd. Zoals eerder werd vermeld, is de markttoegang voor het verhandelen van hun flexibiliteit en andere opties voor het financieel benutten van hun potentieel beperkt in aantal voor bedrijven met lage belastingen. Een scenario voor de beoordeling van het economisch potentieel en de verwachte vergoedingen blijft dus hypothetisch. Het in hoofdstuk VII gebruikte keuze-experiment vormt een methode waarbij een casus voor deelname aan de vraagrespons zo concreet mogelijk wordt beschreven, zodat de gegeven antwoorden zo realistisch mogelijk zijn. De resultaten kunnen echter slechts in beperkte mate worden gegeneraliseerd. Gezien de beperkte ervaring van bedrijven op dit gebied en de onduidelijke regelgeving zijn de verwachte vergoedingen indicatief. Men kan stellen dat zij gevoeliger zijn voor de voorspelbaarheid dan voor de duur of de frequentie van een interventie voor VR-doeleinden en verschillen tussen de toestellen.

Onze methoden voor het inschatten van het theoretisch en technisch potentieel en de inzetbaarheid ervan, omvatten bottom-upberekeningen op basis van empirisch geëvalueerde verbruiksgegevens en de beschikbaarheid van toestellen, resp. optimaliseringsmodellen. Deze schattingen hebben ertoe geleid dat 17-25% van het flexibele elektriciteitsverbruik door bedrijven kan worden geleverd voor VR (technisch potentieel) en dat ongeveer 35% technisch gezien kan worden ingezet. Het lagere technische potentieel is afhankelijk van voorzichtige aannames over de mate waarin een apparaat voor VR-doeleinden kan worden gebruikt, zonder dat de functionaliteit ervan afneemt of dreigt af te nemen. De modelleringsbenadering heeft geleid tot een hogere technische inzetbaarheid, hetgeen wijst op een groter potentieel als deze technische mogelijkheden en aspecten van comfort en acceptatie sterker worden benadrukt. Vanuit dit oogpunt kunnen de grenzen tussen het technisch en praktisch potentieel niet los van elkaar worden gezien.

Praktische implementatie

Hoewel VR in de minder energie-intensieve sectoren ongebruikelijk is, hoeft het wiel niet opnieuw te worden uitgevonden om middelen te vinden voor het bevorderen van de vraag. Veel succesvolle beleidsmaatregelen kunnen worden overgeheveld van het EE-beleid of zowel voor EE als voor VR dienen, aangezien EE- en VR-maatregelen zelfs tot synergiën kunnen leiden. Voor een doeltreffend beleid moeten de kadervoorwaarden (met inbegrip van de bijbehorende regelgeving) worden gewijzigd om VR aantrekkelijker te maken. Aangenomen mag worden dat de relevantie met een groter aandeel van hernieuwbare energiebronnen zal toenemen, maar de hoekstenen kunnen reeds nu worden gelegd door middel van bevordering van besturingstechnologieën, beheerssystemen en automatisering. In vergelijking tot het grotere potentieel per bedrijf in de energie-intensieve sectoren, kunnen de minder energie-intensieve, maar regionaal verspreide bedrijven profiteren van hun beschikbare flexibiliteit op het niveau van de distributienetwerken.

Of een bedrijf, apparaat of proces beter gekwalificeerd is voor EE- of VR-maatregelen is afhankelijk van verschillende factoren: hoge belastingen wijzen op een hoog potentieel voor beide, maar de inzetbaarheid wordt bepaald door bedrijfs- en technologische kenmerken. Deze determinanten kunnen op vergelijkbare wijze voor EE en VR worden beschreven. Een energie-intensief proces dat op een bepaald moment nodig is, onvoorspelbaar is of niet onderbroken kan worden, is niet geschikt voor VR, maar wel voor EE. Hoewel de efficiëntie van een proces kan worden verbeterd door middel van het gebruik van efficiëntere technologieën, is VR specifieker en vereist het veranderingen in de processen zelf. Het gevolg hiervan is dat bij de beoordeling van de mogelijkheden van apparaten voor VR of EE rekening moet worden gehouden met de verschillende geschiktheid van apparaten voor VR of EE.

2.3.2 Vooruitzichten en aanbevelingen

De theoretische taxonomie en classificatie van barrières is algemeen geaccepteerd en bevestigd, met methoden die vergelijkbaar zijn met de methoden die in dit proefschrift worden gebruikt. Om op betrouwbare wijze de details van deze beïnvloedende factoren en hun invloed op de besluitvorming en de implementatie van energiegerelateerde maatregelen te bepalen, zijn goede evaluatie-instrumenten nodig. De factoranalyse ter bepaling van de belangrijkste invloedsfactoren heeft geleid tot bevredigende categorieën, maar afhankelijk van de context was het moeilijk om de factoren duidelijk aan de verschillende dimensies toe te wijzen. Toekomstig onderzoek zou zich kunnen richten op de ontwikkeling van instrumenten voor de systematische beoordeling van de belangrijkste analytische dimensies van energiegerelateerde maatregelen. Methoden voor het testen van theorieën en het construeren van items kunnen worden gebruikt om verschillende en gestandaardiseerde schalen te ontwikkelen, met hoge kwaliteitscriteria voor validiteit en betrouwbaarheid.

De resultaten van dit proefschrift maakten de relatie tussen beïnvloedende factoren en hun relevantie tegen de achtergrond van bedrijfskenmerken, maatregelen en besluitvormingsfasen duidelijk. Studies over de mogelijkheden van energiegerelateerde maatregelen en hun implementatie moeten altijd een holistische benadering nastreven, waarbij rekening wordt gehouden met al deze dimensies. De in dit proefschrift voorgestelde indeling in categorieën kan op deze wijze bijdragen aan een betere evaluatie van het potentieel en de basis vormen voor de ontwikkeling van gestandaardiseerde schalen.

Het verband tussen het technisch en praktisch potentieel houdt in dat bijvoorbeeld besturingstechnologieën kunnen helpen, het technisch potentieel te maximaliseren door technische mogelijkheden volledig te benutten en technische oplossingen te gebruiken om een groter praktisch potentieel aan te boren, zonder de bereidheid te verliezen, het potentieel te benutten, d.w.z. dat het potentieel toeneemt en het verschil tussen het technisch en het praktisch potentieel afneemt. Het maximale potentieel kan worden benut wanneer meer details bekend zijn over de aanvaardbaarheid van specifieke maatregelen. De algemene bereidheid om VR te implementeren is van cruciaal belang, maar de aanvaardbaarheid van een bepaalde maatregel hangt ook af van details zoals het individuele apparaat, de kenmerken van een bedrijf en de details van de concrete implementatie (bv. de voorspelbaarheid van de interventie). De verwachte financiële inkomsten zijn hoger wanneer de maatregelen gepaard gaan met ongemakken of nadelen. Een nauwkeurigere bepaling van het economisch potentieel hangt derhalve ook af van incentieven, zoals de ontwikkeling van bedrijfsmodellen, regelgeving en de specifieke opzet van de maatregelen, en vereist verder onderzoek.

Gelukkig kan de bereidheid worden verhoogd door gunstige voorwaarden te ontwerpen, waarbij gebruik wordt gemaakt van de bevindingen over de relatie tussen beïnvloedende factoren en bereidheid. De veronderstellingen die in dit proefschrift worden gemaakt voor het inschatten van het technisch flexibiliteitspotentieel en de inzetbaarheid ervan, zijn

gebaseerd op andere literatuur, maar niet noodzakelijkerwijs gebaseerd op praktische ervaringen. De afweging tussen het meest effectieve gebruik van flexibiliteit enerzijds en het handhaven van een aanvaardbaar niveau van routine en comfort anderzijds dient dus te worden geëvalueerd. Veldstudies kunnen verschillende scenario's evalueren om meer ervaring op te doen en het praktisch potentieel beter te bepalen middels realistische metingen in de geïdentificeerde doelgroepen.

Wanneer energiegerelateerde maatregelen in bedrijven worden overwogen, vooral in minder energie-intensieve bedrijven, is het een feit dat energie niet de kernactiviteit van deze bedrijven vormt. Om maatregelen te kunnen implementeren, moeten zij een strategische waarde krijgen. Hoewel er veel onderzoek wordt gedaan naar de barrières die een succesvolle implementatie van dergelijke maatregelen in de weg staan, moet een succesvolle implementatie potentiële drijfveren aan het licht brengen, zoals een betere stuurbaarheid van apparaten en daarmee gepaard gaand meer comfort, en de mogelijkheid om het imago van het bedrijf in de ogen van de klant te verbeteren. Dit laatste bleek relevant te zijn in de dienstensector, evenals de houding ten opzichte van maatregelen en hun relevantie voor de energietransitie. Deze niet-energetische voordelen kunnen relevant zijn, vooral indien economische incentieven gering zijn.

Bij de besluitvorming over een specifieke energiegerelateerde maatregel hangt het van de netwerk- en leveringssituatie af of EE of VR meer waarde hebben. Bovendien kunnen verschillende net- of marktgestuurde situaties elkaar tegenwerken, bijvoorbeeld wanneer flexibiliteit aan de vraagzijde vereist is om de stabiliteit van het net of de integratie van hernieuwbare energiebronnen te waarborgen. Om op passende wijze op deze situaties te reageren, moet een uniform stimuleringsinstrument voor de marktdeelnemers worden ontwikkeld, bijvoorbeeld een variabel tarief dat reeds rekening houdt met de specifieke situatie en dus een prioritering van de systeemvereisten impliceert door middel van stimulering van de bevoorrechte respons op de vraag. Dit vereist op zijn beurt dat prioriteiten duidelijk zijn en dat de regelgeving wordt geharmoniseerd.

3 Zusammenfassung und Schlussfolgerungen

Die langfristige Energiestrategie der EU strebt eine wachsende, moderne, wettbewerbsfähige und klimaneutrale Wirtschaft bis 2050 an, mit dem Ziel, den globalen Temperaturanstieg unter 2°C oder besser 1,5°C zu halten. Energieeffizienz und die Erhöhung des Anteils erneuerbarer Energien sind Schlüsselelemente dieser Vision.

Die Verbesserung der Energieeffizienz ist seit Jahrzehnten ein Thema, aber trotzdem sind die Potenziale noch lange nicht ausgeschöpft und Deutschland verfehlt das gesetzte Ziel der Verbrauchseinsparungen für 2020. Deutschland hat bei der Integration erneuerbarer Energien bisher gute Leistungen erbracht, aber der steigende Anteil wird zu Herausforderungen bei der Bewältigung der Volatilität der Erzeugung führen. Die Regulierungen zur Nutzung der Flexibilitätspotenziale zur Unterstützung der Integration erneuerbarer Energien sind noch wenig entwickelt. Offensichtlich gibt es Nachholbedarf bei der Erschließung von Energieeffizienz- und Verbrauchsflexibilitätspotenzialen.

Der Schwerpunkt dieser Arbeit liegt darin, diese Wissenslücken zu schließen, indem Möglichkeiten untersucht werden, wie zur Energiewende durch Verbesserung der Energieeffizienz und Verbrauchsflexibilität beigetragen werden kann. Unternehmen in Deutschland werden beispielhaft betrachtet, um die Potenziale, deren Determinanten und Herausforderungen zu veranschaulichen. Dabei sind erhebliche Potenziale hinsichtlich Energieeffizienz (EE) und Verbrauchsflexibilität (demand response, DR) zu erwarten.

Diese Arbeit widmet sich der zentralen Frage:

Wie können Energieeffizienz und Verbrauchsflexibilität in Unternehmen synergetisch realisiert werden?

Um diese Forschungsfrage zu beantworten, werden in der Arbeit die folgenden Teilfragen behandelt:

FF 1 Wie können Energieeffizienzmaßnahmen in Unternehmen erfolgreich umgesetzt werden und welche Einflussfaktoren sind zu berücksichtigen?

FF 2 Welche Unternehmen sind Zielgruppen für Verbrauchsflexibilität im Dienstleistungssektor und wie groß ist ihr Potenzial?

FF 3 Welche Determinanten beeinflussen das Flexibilitätspotenzial in Unternehmen des Dienstleistungssektors?

FF 4 Wie können wir Synergien zwischen Verbrauchsflexibilität und Energieeffizienz nutzen?

Grundlage für die Beantwortung dieser Forschungsfragen sind sieben unabhängige Publikationen, die Potenziale, Einflussfaktoren und Empfehlungen für die praktische Umsetzung von energiebezogenen Maßnahmen in Unternehmen bewerten.

Kapitel II: Lernende Energieeffizienz- und Klimaschutznetzwerke als Unterstützung für fundierte Entscheidungen zur Erschließung von Energieeffizienzpotenzialen in Unternehmen
Beantwortet die Frage, wie fundierte Entscheidungen über Energieeffizienzpotenziale in Unternehmen ermöglicht werden können.

Kapitel III: Anpassung von Energieeffizienzmaßnahmen an Zielgruppen - Ansätze zu Querschnittstechnologien und Hemmnissen in der Industrie
Untersucht, wie Energieeffizienzmaßnahmen auf verschiedene Unternehmenstypen zugeschnitten werden müssen.

Kapitel IV: Weichenstellung für die Verbrauchssteuerung im Dienstleistungssektor
Beschreibt die regulatorische Situation von DR in Deutschland und beantwortet die Frage, wo aus Sicht der Stakeholder die Potenziale des Dienstleistungssektors liegen.

Kapitel V: Verbrauchsflexibilität im Dienstleistungssektor – theoretische, technische und praktische Potenziale
Liefert eine Schätzung des DR-Potenzials in Unternehmen des Dienstleistungssektors und zeigt, welche Faktoren das Potenzial beeinflussen.

Kapitel VI: Der Flexibilitätseinsatz des Dienstleistungssektors - ein Modellierungsansatz für die Nachfragesituation mit Erkenntnissen aus einer Marktforschungsstudie
Konzentriert sich auf den möglichen Beitrag der Unternehmen des Dienstleistungssektors zum Lastmanagement und zur Integration von erneuerbaren Energiequellen.

Kapitel VII: Wie viel Verbrauchsflexibilität kann man mit einem Euro kaufen? Ergebnisse aus einem Choice-Experiment mit Unternehmen des deutschen Handels und Dienstleistungssektors
Schätzt den erwarteten finanziellen Gewinn von Unternehmen für ihre Verbrauchsflexibilität.

Kapitel VIII: Energieeffizienz und Verbrauchsflexibilität - zwei Seiten derselben Medaille?
Erörtert, wie Erfahrungen mit Energieeffizienzmaßnahmen genutzt werden können, um auch die Verbrauchsflexibilität zu unterstützen.

Tabelle IX-1 zeigt die Inhalte und Schwerpunkte der Kapitel.

Tabelle IX-1: Übersicht der Kapitel, Forschungsfragen, Hauptthemen, Fokus und Methoden

	Forschungs-fragen				**Haupt-themen**			**Sektor**		**Maßnahmen**		**Ansätze/ Analysen**
Kapitel	*FF 1*	*FF 2*	*FF 3*	*FF 4*	Potenziale	Determinanten	Umsetzung	Industrie	Service/ GHD	Energieeffizienz	Verbrauchs-flexibilität	Methode
II	x				x		x	x		x		pre-post Evaluation
III	x					x	x	x		x		Faktoranalyse, Signifikanztests, Regressionsanalysen
IV		x	x		x	x			x		x	qualitative Stakeholder Analyse
V		x	x		x	x			x		x	math. Ansatz, Regressionsanalyse
VI		x	x		x		x		x		x	Modellierung
VII			x		x	x			x		x	Choice-Experiment/ bedingte Bewertung
VII	x		x	x		x	x		x	x	x	Politikanalyse, Faktoranalyse, Regressionsanalyse

3.1 Zusammenfassung der Ergebnisse

In diesem Abschnitt werden die wichtigsten Ergebnisse der Veröffentlichungen vorgestellt und diskutiert.

Kapitel II: Lernende Energieeffizienz- und Klimaschutznetzwerke als Unterstützung für fundierte Entscheidungen zur Erschließung von Energieeffizienzpotenzialen in Unternehmen

Kapitel II analysiert die Daten der Begleitforschung von über 350 Unternehmen aus dem verarbeitenden Gewerbe, die an den "Learning Energy Efficiency Networks" (lernende Energieeffizienz- und Klimaschutznetzwerke, LEEN) teilgenommen haben. LEEN kombiniert Aspekte von Informationen (wie Audits), geteilte Erfahrungen und moderierte Lernprozesse. Die gesammelten Daten ermöglichen die Bewertung von Erwartungen und Hemmnissen, sowie Informationen, Kooperationen und Erfahrungen der Unternehmen, die den Erfolg der Umsetzung beeinflussen können. Die Unternehmen werden bei allen Schritten zur Verbesserung der Energieeffizienz unterstützt, beginnend mit einer Analyse der Situation und Vorschlägen für rentable Maßnahmen. Ein Schwerpunkt der Analysen liegt auf den Erwartungen und Bedürfnissen der Unternehmen und wie sie erfüllt werden können.

Das Hauptinteresse der Unternehmen liegt auf praktischem Wissen und spezifischen Informationen, d.h. einer Analyse der energetischen Situation, Möglichkeiten zur Senkung der Energiekosten und Informationen über spezifische Maßnahmen und Technologien. Die Erwartungen der Unternehmen betrafen auch die Entscheidungsunterstützung und die Senkung der Transaktionskosten durch Erfahrungsaustausch, die über das hinausgehen, was typische Energieaudits bieten. Die Erwartungen konnten durchaus erfüllt werden. Die Teilnahme an den Netzwerken hat Barrieren durch fehlendes Energiemanagement und fehlender Informationen oder Marktübersichten abgebaut. Die wirtschaftlichen Aspekte der Maßnahmen konnten nicht verbessert werden. Obwohl sich einige Bewertungen der Hemmnisse im Laufe des Netzwerkprozesses nicht verändert haben, haben fast alle Unternehmen (96%) vorgeschlagene Energieeffizienzmaßnahmen umgesetzt und 75% gaben an, dass diese Maßnahmen ohne die Netzwerke nicht umgesetzt worden wären. Die quantitative Überwachung durch den Energiemanager und den beratenden Ingenieur ergab eine jährliche durchschnittliche Effizienzsteigerung von 2,1% (gegenüber dem durchschnittlichen Effizienzfortschritt in der Industrie von ca. 1%). Neben der Quantifizierung der Ergebnisse profitierten die Unternehmen auch von den Netzwerken, indem sie Kontakte zu anderen Unternehmen knüpften und die Möglichkeit zur Zusammenarbeit in Energiefragen oder für andere Zwecke erhielten.

Ein Mehrwert gegenüber anderen informativen Beratungen wie Audits ergibt sich aus der Begleitung über drei bis vier Jahre, da zu unterschiedlichen Zeiten im Prozess unterschiedliche Probleme auftreten können. Über eine reine Beratung oder

Information hinaus fungieren die Netzwerke so als Befähiger und bieten den Unternehmen die notwendige Unterstützung und das praktische Wissen. Es ist davon auszugehen, dass die Anpassung des Programms an die Bedürfnisse der Teilnehmer ein wesentlicher Erfolgsfaktor des Konzepts der Netzwerke ist. Vor diesem Hintergrund ist zu berücksichtigen, dass Hemmnisse nicht nur mit Maßnahmen zusammenhängen, sondern auch aus den Routinen, Prozessen und anderen Merkmalen eines Unternehmens stammen. Um die Energieeffizienzpotenziale der Unternehmen voll auszuschöpfen, müssen die Maßnahmen auf deren Merkmale und Rahmenbedingungen zugeschnitten sein.

Kapitel III: Anpassung von Energieeffizienzmaßnahmen an Zielgruppen - Ansätze zu Querschnittstechnologien und Hemmnissen in der Industrie

In Kapitel III wird ein genauerer Blick auf übergreifende Energieeffizienzmaßnahmen und -hemmnisse geworfen und wie diese mit verschiedenen Unternehmenstypen zusammenhängen. Um Zielgruppen zu finden, werden die wichtigsten Hemmnisse und ihre Relevanz für verschiedene Unternehmenstypen identifiziert. Dies eröffnet die Möglichkeit einer besseren Abstimmung von Energieeffizienzmaßnahmen oder Dienstleistungen auf Unternehmen und erhöht die Wahrscheinlichkeit, dass Maßnahmen tatsächlich umgesetzt werden.

Die Analysen zeigen, dass Hemmnisse im Zusammenhang mit der Verfügbarkeit von Zeit und Geld an erster Stelle stehen, was die geringere Priorität von Energiefragen im Vergleich zu Kerngeschäftsfragen widerspiegelt. Eine Kategorisierung der Hemmnisse führte zu den Hauptkategorien "finanzielle/wirtschaftliche Hemmnisse", "Einschränkungen durch der technisch/strukturellen Gegebenheiten", "Motivation/interne Relevanz" und "Informationen oder externe, marktbedingte Defizite". Diese Kategorien sind vergleichbar mit den in der Literatur vorgeschlagenen Taxonomien von Hemmnissen. Die am höchsten eingestufte Kategorie der wirtschaftlichen Hemnisse bezieht sich auf die finanziellen Möglichkeiten oder die Bewertung der Rentabilität der Maßnahme. Diese Bewertung wird oft mit ungeeigneten Risikoindikatoren wir kurzer Amortisationszeiten vorgenommen. Dieses Hemmnis ist insbesondere bei Unternehmen vorhanden, die ihre Entscheidungen überwiegend auf finanzielle Aspekte stützen oder die Teil eines Mutterkonzerns sind und daher nicht selbstständig über Investitionen entscheiden können. Die am zweithöchsten bewertete Kategorie (technische/strukturelle Gegebenheiten) kann mit Beratung, Energiemanagement-Tools oder -Dienstleistungen beeinflusst werden. Motivationsbarrieren sind vor allem in größeren Unternehmen, Unternehmen mit niedrigen Energiekosten oder ohne energieintensive Prozesse relevant. Insbesondere letztere Merkmale beziehen sich auf kleine Energieeffizienzpotenziale und könnten somit Maßnahmen unattraktiv machen. Wenn Unternehmenstypen in Verordnungen oder Richtlinien unterschieden werden, orientieren sich diese in der Regel an der Größe der Unternehmen. Unsere Analysen ergaben, dass spezifische Hemmnisse für KMU

(kleine und mittlere Unternehmen, <250 Beschäftigte) stärker und häufiger sind als für GU (große Unternehmen), was auf eine größere Heterogenität innerhalb der KMU hinweist. Die Anzahl der umgesetzten Energieeffizienzmaßnahmen ist in großen Unternehmen höher, wahrscheinlich aufgrund eines größeren Produktionsstandortes und damit einhergehend mehr Anlagen und Technologien. Dennoch stoßen verschiedene Unternehmenstypen auf unterschiedliche Hemmnisse und sind daher für verschiedene Arten von Maßnahmen geeignet.

Die vorgeschlagenen Energieeffizienzmaßnahmen müssen sich an den Eigenschaften des Unternehmens orientieren, nicht nur an den technischen Möglichkeiten. In der Regel sind viele Maßnahmen technisch sinnvoll, dennoch werden nicht alle ergriffen. Größe und Branche erwiesen sich als relevante Faktoren, aber auch die Autonomie des Unternehmens, die Kundennähe, die Art und Weise, wie Entscheidungen getroffen werden, und die Energieintensität spielen eine Rolle bei der Suche nach geeigneten Maßnahmen. Um die Umsetzungsrate zu verbessern, müssen Hemmnisse überwunden werden. Zeit- und Geldknappheit scheinen die ersten Fallstricke zu sein, an denen mögliche Maßnahmen scheitern. Besonders wenn Energie kein strategisches Thema ist, sind die Anreize für große Anstrengungen gering. Eine vorausschauendere Beurteilung der Rentabilität von Maßnahmen und attraktive Finanzierungsmöglichkeiten könnten diese Schwierigkeiten überwinden. One-Stop-Lösungen wie ein Energieservice könnten den organisatorischen Aufwand und den Zeitaufwand verringern. In der Regel kann die Entscheidungsfindung schneller erfolgen, wenn sie innerhalb des Unternehmens erfolgt (und nicht z.B. durch Muttergesellschaften). Ein Instrument zur Selbsteinschätzung für Unternehmen auf der Grundlage der genannten Einflussfaktoren, könnte den Aufwand und die Zeit zur Identifizierung geeigneter Maßnahmen reduzieren.

Kapitel IV: Weichenstellung für Verbrauchsflexibilität im Dienstleistungssektor

Ein flexiblerer Strombedarf kann dazu beitragen, die Integration volatiler erneuerbarer Energien zu ermöglichen. Im Vergleich zu den Industriesektoren wurde der Dienstleistungssektor in dieser Hinsicht bisher weniger untersucht. Im Vergleich zu Branchen mit höherem Energieverbrauch und Flexibilitätspotenzial pro Unternehmen ist die Möglichkeit zur Marktteilnahme für die weniger energieintensiven Unternehmen des Dienstleistungssektors geringer. In Deutschland können flexible Lasten am Regelenergie- und Spotmarkt gehandelt werden. Das Engpassmanagement kann im Rahmen der abschaltbaren Lasten (AbLaV) eingesetzt werden. Die flexiblen Verbraucher müssen sich präqualifizieren (d.h. den technischen Anforderungen entsprechen), um teilnehmen zu können. Vor kurzem wurden die Mindestgebotsgrößen angepasst, um auch die Teilnahme kleinerer Lasten (zwischen 1 MW und 5 MW) zu ermöglichen, und die Lasten können aggregiert werden, z.B. durch Dritte wie Aggregatoren. Die standardisierten Prozesse für Verträge zwischen Aggregatoren, Bilanzierungsmanagern und Lieferanten sind jedoch noch nicht klar definiert und stellen regulatorische Hindernisse dar. Darüber hinaus ist die

"Stromnetzentgeltverordnung" (StromNEV) eine weitere regulatorische Barriere für die Nutzung von DR-Potenzialen, die der Verbrauchsflexibilität durch Anreize für eine konstante, berechenbare Nachfrage entgegenwirkt. So sind besonders große, energieintensive Unternehmen (z.B. Industrie) oder Drittanbieter (z.B. virtuelle Kraftwerke) in die oben genannten Märkte eingebunden. Viele kleinere Verbraucher erfüllen immer noch nicht die Präqualifikationskriterien. Aggregation ist für sie derzeit allerdings selten lohnend. Einige größere Unternehmen aus dem Dienstleistungssektor nutzen ihre flexible Nachfrage, um Spitzenlasten zu minimieren, nutzen flexible Tarife oder optimieren den Strombezug. Daher ist davon auszugehen, dass das DR-Potenzial des Dienstleistungssektors weitgehend ungenutzt ist, aber für das Netzmanagement oder zur Unterstützung der Integration volatiler erneuerbarer Energien wertvoll sein könnte.

Die Subsektoren Handel, Restaurants, Hotels und Büros erscheinen besonders vielversprechend. Zusammen sind sie für mehr als 50% des gesamten Stromverbrauchs des GHD-Sektors (Gewerbe, Handel, Dienstleistungen) verantwortlich. Ein erheblicher Teil des Stromverbrauchs in diesen Subsektoren wird durch flexibel einsetzbare Geräte verursacht. Diese flexiblen Querschnittstechnologien sind Kühlung, Heizung, Klimatisierung und Belüftung sowie elektrische Warmwasserbereitung. Stakeholder-Interviews wurden durchgeführt, um mehr darüber zu erfahren, wie die flexible Nachfrage in den ausgewählten Zielbranchen genutzt werden kann. In Büros ist DR bisher kein Thema, aber vor allem in den Bereichen Klimatisierung und Lüftung (VAC) finden sich Potenziale. In großen, modernen Gebäuden sind bereits Steuerungstechnologien vorhanden, die die Nutzung der flexiblen Anforderungen erleichtern könnten. Die Befragten wiesen darauf hin, dass die Maßnahmen nicht den Komfort der Mitarbeiter einschränken dürfen, da sie befürchten, dass die Qualität der Arbeit leiden könnte. In diesem Fall kann das Verhalten der Mitarbeiter die Maßnahmen stören, z.B. wenn die Klimaanlage für DR verwendet wird und die Mitarbeiter die Fenster öffnen. In der Lüftungs- und Klimatechnik hat auch der Handel Potenzial und im Lebensmittelbereich können Kühl- und Gefriergeräte für DR eingesetzt werden. Je nach Filiale können spezifische Geräte wie Backmaschinen oder Unterhaltungselektronik das Potenzial erhöhen. Diese Potenziale wurden teilweise erkannt und es werden Möglichkeiten zu ihrer Nutzung geprüft. Die Aggregation von Potenzialen könnte im Einzelhandel einfacher sein, z.B. wenn mehrere Filialen zu einem Unternehmen gehören. Auch die Entscheidungsfindung ist vereinfacht, wenn nur die Zentrale überzeugt werden muss und die Maßnahmen in den Filialen umgesetzt werden. Die regulären Phasen der Sanierung können genutzt werden, um die notwendigen Steuerungen zu installieren. Im Gastgewerbe (Hotels/Restaurants) verursachen Küchengeräte neben VAC und Kühlgeräten hohe Lasten und kommen für DR in Frage. In Großküchen existieren diese Steuerungstechnologien oft bereits zum Zweck der Reduktion von Lastspitzen, aber den Küchengeräten fehlt es in der Regel an Flexibilität und sie müssen bei der Zubereitung der Gerichte für die Gäste auf Abruf bereit sein. Alle Stakeholder sind sich über die allgemeine Relevanz von DR einig, haben

aber Bedenken hinsichtlich der Kosten oder der möglichen Beeinträchtigung von Arbeitsprozessen. Dieses Problem wird insbesondere von den Interessengruppen der Subsektoren thematisiert, wird aber von Experten und Technologielieferanten als überbewertet angesehen. Es wurden auch Faktoren genannt, die die Umsetzung erleichtern, z.B. regelmäßige Renovierung oder Zusatznutzen wie eine bessere Steuerung und Überwachung der Geräte und damit verbundene Synergien mit Energieeffizienzmaßnahmen. Die Neufassung der EPBD (Europäische Kommission, 2018; Richtlinie 2018/844) stärkt die Möglichkeiten von Gebäuden für DR und kann so die Verbreitung dieser Technologien unterstützen. Dies betrifft auch den geringeren finanziellen Aufwand für die technische Ausrüstung zur zukünftigen Realisierung von DR. Energiemanagement, technologische Entwicklungen und regulatorische Änderungen können als Türöffner für DR fungieren, insbesondere wenn dies eine vereinfachte Präqualifikation und Aggregation von Potenzialen ermöglicht. Flexible Tarife könnten eine weitere Option sein, um die Teilnahmekriterien und Hindernisse der Flexibilitätsmärkte zu umgehen. Unter der Prämisse eines steigenden Anteils erneuerbarer Energien, Veränderungen im Energiesystem und einer größeren Relevanz flexibler Stromnachfrage könnte die finanzielle Attraktivität steigen.

Kapitel V: Verbrauchsflexibilität im Dienstleistungssektor – theoretische, technische und praktische Potenziale

Im Anschluss an Kapitel IV liegt eine vertiefte Untersuchung der ausgewählten Zielgruppen Büros, Handel und Gastgewerbe zur Quantifizierung ihrer Flexibilitätspotenziale nahe. Derzeit werden die Potenziale kaum genutzt, nur ein kleiner Teil der Unternehmen prüft ihre Flexibilitätsmöglichkeiten oder führt DR durch. Die Ergebnisse der qualitativen Studie werden bestätigt, in der große Unternehmen im Allgemeinen und insbesondere Restaurants und der Lebensmitteleinzelhandel als Subsektoren mit höherem Interesse an DR identifiziert wurden. Diese Unternehmenstypen sind auch diejenigen mit der höchsten Bereitschaft, DR-Maßnahmen durchzuführen. Die quantitative Bewertung umfasst das theoretische Potenzial (der Energieverbrauch flexibler Geräte), das technische Potenzial (d.h. Berücksichtigung der technischen Einschränkungen der Geräte, um ihren Bedarf flexibler zu gestalten) und das praktische Potenzial (d.h. Berücksichtigung der Bereitschaft der Unternehmen). Als flexible Querschnittstechnologien gelten Lüftung, Klimatisierung, Kühlen und Gefrieren, Wärmepumpen, Nachtspeicherheizungen und elektrische Warmwasserbereitung. Insgesamt weisen die Subsektoren Lebensmittelhandel, und Restaurants das höchste theoretische, technische und praktische Potenzial auf. Den höchsten Grad an Flexibilität bieten Klimatisierung und Kühlung (Kühlschränke und Kühlräume). Unsere Annahmen zu technischen Einschränkungen sind sehr konservativ und gehen von einem technischen Potenzial von 1-2 Stunden pro Gerät und Tag aus. Das gesamte technische Potenzial unserer ausgewählten Sektoren beträgt fast 20% des theoretischen Potenzials. Betrachtet man nur die Unternehmen, die sich bereit erklärt haben, DR durchzuführen, so liegt das

praktische Potenzial noch bei etwa 25% des gesamten technischen Potenzials. Unterschiede zwischen den Geräten hinsichtlich der Einsatzbereitschaft für DR sind zu erwarten: Die Flexibilisierung von Lüftungs- und Klimaanlagen wird relativ gut akzeptiert; Kühlgeräte scheinen weniger kritisch in der Nutzung zu sein als Geriergeräte. Unter Einbezug aller anderen flexiblen Geräte in den beschriebenen Subsektoren ergeben unsere Schätzungen ein theoretisches Potenzial von ca. 22 TWh (~ 35% des gesamten Stromverbrauchs der Subsektoren), 4 TWh technisches Potenzial und 1 TWh praktisches "Vorreiter"-Potenzial. Die Bereitschaft (d.h. die Absicht, DR durchzuführen) hängt von den Bedingungen und den damit verbundenen Treibern und Hemmnissen ab. Insbesondere die wahrgenommene Bedeutung von DR für die Energiewende, die Eignung der Geräte für DR, die finanzielle Attraktivität und das Risiko der Störung interner Prozesse spielen eine wichtige Rolle. Sie spiegeln die Einstellung, die technischen Anforderungen, die wirtschaftliche Attraktivität und die organisatorische Eignung von DR wider. Ausgehend von einem geringeren Potenzial pro Unternehmen, spielen finanzielle Fragen und die generelle Einstellung zu DR für kleine Unternehmen eine stärkere Rolle. Für größere Unternehmen beeinflussen insbesondere technische Einschränkungen die Bereitschaft zur Durchführung von DR. Neben der allgemeinen Bereitschaft ist auch die Priorisierung von DR durch das Management wichtig für die Entscheidungsfindung. Dabei spielen insbesondere der positive Imageeffekt von DR und der organisatorische Aufwand der Maßnahmen eine Rolle. Zusätzlich erhöht die Durchführung eines Energieaudits (d.h. Erfahrungen mit Energiemaßnahmen) die Priorität von DR in den Unternehmen.

Kapitel VI: Der Flexibilitätseinsatz des Dienstleistungssektors - ein Modellierungsansatz für die Nachfragesituation mit Erkenntnissen aus einer Marktforschungsstudie

Der Schwerpunkt dieses Kapitels liegt auf dem technischen und praktisch flexiblen Stromverbrauch, der tatsächlich eingesetzt werden kann. Im Vergleich zu den Potenzialen, die von den Unternehmen bereitgestellt werden können, nimmt dieser Ansatz die Perspektive der erforderlichen Flexibilität ein und bewertet die Übereinstimmung von Potenzialen und Flexibilitätsbedarf des Stromnetzes. Die Übereinstimmung wird unter Berücksichtigung der Lastkurven der verfügbaren flexiblen Geräte und der Residuallastkurve berechnet, wobei z.B. auch die Erzeugung erneuerbarer Energien, Wetterbedingungen und die Entwicklung des Energieverbrauchs berücksichtigt werden. Die Schätzungen basieren auf den gleichen Verbrauchsdaten für flexible Geräte wie in Kapitel V und einem Szenario mit 50% Anteil der erneuerbaren Energien, d.h. dem Zielanteil für 2030.

Wenn alle ausgewählten Subsektoren an DR teilnehmen, kann ein technischer Flexibilitätseinsatz von 7,7 TWh erreicht werden, der größte technische Flexibilitätseinsatz kann in den Bereichen Handel (3,4 TWh) und Gastgewerbe (2,6 TWh) sowie bei den Geräten Lüftung und Klimatisierung (VAC, 2,8 TWh) und Kühl- und

Gefrierprozesse (2,6 TWh) erfolgen. Da die technischen Potenziale nicht auf 1-2 Stunden pro Gerät und Tag beschränkt sind, sondern sich aus dem Stromverbrauchsverhalten der Verbraucher ergeben, ist die berechnete einsetzbare Flexibilität des Stroms höher als in Kapitel V berechnet. Unter Berücksichtigung der Entwicklungen bis 2030 könnten sich einige Potenziale als kleiner erweisen, da der Stromverbrauch von Geräten durch Effizienzsteigerungen sinken könnte. Die Einsatzfähigkeit der Flexibilität variiert je nach Wetterlage und Jahreszeit. Während AC nur in den Sommermonaten verfügbar ist, werden Heizgeräte wie Nachtspeicherheizungen und Wärmepumpen in der heißen Sommersaison nicht betrieben. Die Verfügbarkeit von Flexibilität fällt teilweise mit dem Überschuss an erneuerbaren Energiequellen (RES) zusammen: Etwa 20% (0,5 TWh) des gesamten RES-Überschusses von 2,5 TWh könnten von den betrachteten Sektoren aufgenommen werden. In einem weiteren Szenario mit 80% RES (was in vielen Ländern bis 2050 der minimale RES-Anteil sein kann), entspricht die Verfügbarkeit flexibler Lasten häufiger dem RES-Überschuss und etwa 1,6 TWh können von unseren ausgewählten Sektoren aufgenommen werden. Berücksichtigt man für das 50%ige RES-Szenario nur die Unternehmen, die sich zur Teilnahme bereit erklärt haben, so reduziert sich der Verbrauch von flexiblen Geräten auf 16,5%. Dies reduziert den praktischen Flexibilitätseinsatz auf 1,8 TWh (24% des technischen Flexibilitätseinsatzes) und nur 0,1 TWh RES-Überschuss (26% der technisch machbaren Reduktion) können von den ausgewählten Sektoren aufgenommen werden. Es ist jedoch davon auszugehen, dass die Bereitschaft zur Teilnahme an DR in der Zeit bis 2030 steigt, wenn der Wert der flexiblen Nachfrage steigt und technische Standards und die Steuerbarkeit von Geräten die Nutzung von Flexibilitätspotenzialen erleichtern. Unter der Annahme, dass der Strompreis von der Residuallast abhängt, kann der zukünftige Echtzeitstrompreis unter Verwendung der Residuallast von 2030 mit einem Anteil von 50% RES berechnet werden. Aufgrund der geringen Preisspannen im Durchschnitt zwischen zwei aufeinanderfolgenden Stunden wird der finanzielle Wert einer eingesetzten flexiblen MWh Strom auf 23 € geschätzt.

Kapitel VII: Wie viel Verbrauchsflexibilität kann man mit einem Euro kaufen? Ergebnisse aus einem Choice-Experiment mit Unternehmen des deutschen Handels und Dienstleistungssektors

Neben den Flexibilitätspotenzialen des Dienstleistungssektors und ihrer Einsetzbarkeit konnte anhand der Umfragedaten mehr über finanzielle Anreize bei der Teilnahme an DR in Erfahrung gebracht werden. Die Unternehmen, die sich allgemein zu DR bereit erklärten, wurden zu einem Choice-Experiment aufgefordert. Sie wurden zufällig nach einem flexiblen Gerät gefragt und ob sie damit einverstanden wären, es gegen eine Ausgleichszahlung automatisiert für DR einzusetzen. Jedem Unternehmen wurden zwei dieser Szenarien vorgestellt, d.h. es wurde nach zwei verschiedenen Geräten gefragt. Das Szenario variierte in Bezug auf Häufigkeit (zwischen zweimal täglich und einmal

wöchentlich), Dauer (zwischen 30 und 90 Minuten) und Zeitrahmen (zu jeder Zeit vs. nur zu vereinbarten Zeitpunkten) der automatischen Steuerung. Das Experiment ermöglicht es, indikative Durchschnittskosten pro MWh zu schätzen, um die wirtschaftlichen Flexibilitätspotenziale der Unternehmen für die Geräte Lüftung, Klima, Kühlen und Gefrieren zu aktivieren. Viele der Unternehmen haben das Angebot im Experiment entweder allgemein akzeptiert oder generell abgelehnt und die daraus resultierenden Zahlungen dadurch erheblich gespreizt. Es ist davon auszugehen, dass die Unternehmen über mangelnde Markterfahrung und damit Unsicherheit über eine angemessene Bezahlung verfügen und dazu neigen, die Teilnahme an DR aus strategischen oder verhaltensbedingten Gründen zu befürworten oder abzulehnen.

Für die Lüftungs- und Klimatechnik (VAC) liegt die durchschnittlich erwartete jährliche Zahlung der teilnehmenden Unternehmen bei rund 1.400 €. Für die Lüftung erwarteten die Unternehmen jährliche Zahlungen von durchschnittlich 1.200 €, für die Klimatisierung von rund 1.700 €. Es wurde kein Effekt von Dauer und Häufigkeit festgestellt, aber wenn die Flexibilität nur in vereinbarten Zeiträumen gefordert wird, werden die erwarteten Erlöse geringer (um ca. 1/3). Im Vergleich von Lüftung und Klimatisierung verspricht die Klimatisierung ein größeres und kostengünstigeres Potenzial. Das Potenzial ist höher, aber die erwartete Vergütung unterscheidet sich nicht wesentlich von der für flexible Lüftung. Unter Berücksichtigung des durchschnittlichen Stromverbrauchs (technisches Potenzial) der VAC der am Experiment beteiligten Unternehmen könnte das Potenzial von Lüftungsgeräten für ca. 800 €/ MWh und das Potenzial der Klimatisierung für ca. 300 €/ MWh freigesetzt werden (bei einem flexiblen Anteil von 4% des Stromverbrauchs für Lüftung und 11% für Klimatisierung). Für die Kühlung und das Gefrieren liegen die durchschnittlich erwarteten jährlichen Erlöse bei etwa 2.500 €, während die erwartete Zahlung für die flexible Nachfrage von Gefriergeräten im Vergleich zu Kühlgeräten erheblich höher ausfallen muss. Bezieht man diese Zahlen auf den Stromverbrauch, könnte das Potenzial von Kühlung / Gefrieren für durchschnittlich etwa 900 €/ MWh mobilisiert werden. Häufigkeit, Dauer und Zeitrahmen hatten keine Auswirkungen auf diese Zahlen, aber größere Unternehmen erwarten höhere Erlöse.

Kapitel VIII: Energieeffizienz und Verbrauchsflexibilität - zwei Seiten derselben Medaille?

Ein nachhaltiges Energiesystem muss Energieeffizienz und Flexibilität umfassen. Daher ist es von Interesse, beide Konzepte synergetisch zu fördern. Aus Sicht der Unternehmen sind beide Konzepte miteinander verbunden – beide zielen darauf ab, ihren Energieverbrauch zu beeinflussen, aber in der praktischen Umsetzung stellen sie sie vor unterschiedliche Herausforderungen. In allen Subsektoren sind Energieeffizienzmaßnahmen viel häufiger (in etwa 50 % der Dienstleistungs-unternehmen) vertreten als Maßnahmen zur Verbrauchssteuerung (weniger als 10 %). Allgemein sind die Anteile bei großen Unternehmen und den Subsektoren des

Gastgewerbes am höchsten. Energieeffizienzmaßnahmen (EE) werden über alle Querschnittstechnologien hinweg durchgeführt und betreffen vor allem Beleuchtung und Sensoren, Heizung und IT/Energiemanagement. 17% der Unternehmen, die EE-Maßnahmen umgesetzt haben, gaben an, dass mindestens eine der Maßnahmen von der Bundesregierung oder den Bundesländern finanziert wurde. Demand Response (DR)-Maßnahmen werden in der Regel zur internen Bedarfsoptimierung eingesetzt, wie z.B. Vermeidung von Lastspitzen oder optimierter Stromeinkauf. Nur 1% der befragten Unternehmen gaben an, dass sie an den Regelenergiemärkten teilnehmen. Bestimmte Faktoren beeinflussen und unterstützen die Umsetzung von energiebezogenen Maßnahmen (z.B. Audits, Energiemanagementsysteme (EnMS) oder Gebäudemanagementsysteme (BMS) etc.). Die gleichen Unternehmenstypen, die entweder EE- oder DR-Maßnahmen umsetzen, sind diejenigen, die Gebäude- oder Energiemanagementsysteme einsetzen und Audits durchführen. Die Analyse ergab, dass die meisten dieser Faktoren die Wahrscheinlichkeit, beide Maßnahmen durchzuführen, positiv beeinflussen. Dennoch sind Unternehmensmerkmale wie Branche und Größe für die Durchführung von DR-Maßnahmen relevanter als für EE, was darauf hindeutet, dass DR besser zu bestimmten Unternehmenstypen passt, während EE weniger spezifisch ist. EE-Maßnahmen erfordern in der Regel vorrangig einen Wechsel zu effizienteren Geräten oder moderneren Systemen, DR-Maßnahmen können eine Änderung individueller Normen oder Routinen bedeuten, z.B. bei Tarifänderungen oder Vertragsverhandlungen mit Dienstleistern. Die relevanten Faktoren und die Treiber mit dem größten Einfluss bzw. den größten Hemmnissen sind für DR und EE die gleichen, jedoch sind DR-Maßnahmen weniger etabliert und beginnen auf einem anderen Level an praktischer Erfahrung als EE. Beide Arten von Maßnahmen können als Maßnahmen zur Beeinflussung des Energieverbrauchs gesehen werden und werden von den Unternehmen nicht völlig unterschiedlich wahrgenommen. Dies deutet darauf hin, dass Instrumente zur erfolgreichen Förderung von Energieeffizienzmaßnahmen auch dazu dienen könnten, die Steuerbarkeit des Verbrauchs zu fördern.

Etablierte Arten von energieeffizienzpolitischen Instrumenten wurden dahingehend untersucht, ob Aspekte der Verbrauchsflexibilität übertragen oder integriert werden können. Einige Instrumente unterstützen bereits implizit Maßnahmen zur Nachfragesteuerung, z.B. Anreize zur Einführung von Energiemanagementsystemen oder Richtlinien zur Erhöhung der "Intelligenz" eines Gebäudes, die auf einen effizienten und komfortablen Betrieb des Gebäudes, die Möglichkeit zum Laden von Elektrofahrzeugen und die Unterstützung der Nachfragesteuerung in einem modernisierten Strommarkt abzielen. Grundsätzlich können auch andere Instrumente zur Förderung von DR eingesetzt werden, wie die verpflichtende Teilnahme an Energie-Audits und andere Informationsinstrumente (z.B. Energieeffizienznetzwerke), idealerweise kombiniert mit der finanziellen Förderung der identifizierten Maßnahmen. Standardisierungsmaßnahmen könnten auch für DR angewendet werden, z.B. durch eine mit Effizienzstandards vergleichbare Norm für "DR-fähige" Geräte.

Aufgrund des weniger ausgeprägten regulatorischen Rahmens und der stärkeren Spezifität von DR-Maßnahmen in Bezug auf Unternehmenstypen könnten erfolgreiche Maßnahmen noch stärker zugeschnitten werden als EE-Maßnahmen. Für Unternehmen ist der Wert der flexiblen Nachfrage mehr von Marktangeboten und -regulierungen, Wetterbedingungen und dem Bedarf an Flexibilität als bei Energieeffizienz abhängig. Dennoch können die Erfahrungen mit EE als Anstoß für die Umsetzung anderer energiebezogener Maßnahmen dienen und von Synergien profitieren, z.B. durch die Nutzung bereits vorhandener Energiemanagementsysteme.

3.2 Beantwortung der Forschungsfragen

In den folgenden Abschnitten werden die Ergebnisse der einzelnen Kapitel zusammengetragen und zu den Forschungsfragen zusammengefasst.

1. *Wie können Energieeffizienzmaßnahmen in Unternehmen erfolgreich umgesetzt werden und welche Einflussfaktoren sind zu berücksichtigen?*

Für einen erfolgreichen Prozess zur Verbesserung der EE hat es sich als vorteilhaft erwiesen, rentable Maßnahmen vorzuschlagen und Unternehmen in allen Phasen der Entscheidungsfindung und Umsetzung von Maßnahmen zu unterstützen. Auf diese Weise können die meisten relevanten Hemmnisse und Erwartungen hinsichtlich Motivation, Rentabilität und Information berücksichtigt werden. Die Unterstützung ermöglicht es Unternehmen, mit unterschiedlichen Herausforderungen umzugehen, die in verschiedenen Phasen des Prozesses auftreten. Erfahrungsaustausch und Vergleiche mit anderen Unternehmen erhöhen die Motivation und bieten Orientierung. Hemmnisse sind spezifisch für Maßnahmen und Unternehmensmerkmale, insbesondere bezüglich Größe und Branche, die die Energieintensität und Verfügbarkeit von Technologien und Anlagen bestimmen. Darüber hinaus spielen Faktoren wie die Autonomie des Unternehmens, die Kundennähe und Entscheidungsprozesse eine Rolle. Eine gute Umsetzung berücksichtigt diese notwendige Passung und die spezifischen Bedürfnisse der Unternehmen. Die Hauptkategorien der in der Literatur gefundenen Hemmnisse konnten bestätigt werden, d.h. technische, organisatorische, wirtschaftliche, verhaltensbezogene und externe Hemmnisse, während Hemmnisse im Zusammenhang mit Zeit und Geld oft am höchsten eingestuft werden. Um die Risiken des frühen Scheiterns zu mindern, wenn fälschlicherweise davon ausgegangen wird, dass Maßnahmen nicht rentabel wären, sollten Möglichkeiten geschaffen werden, die geeigneten und rentablen Maßnahmen mit geringem Aufwand zu identifizieren.

Allgemeine Erfolgsfaktoren sind:

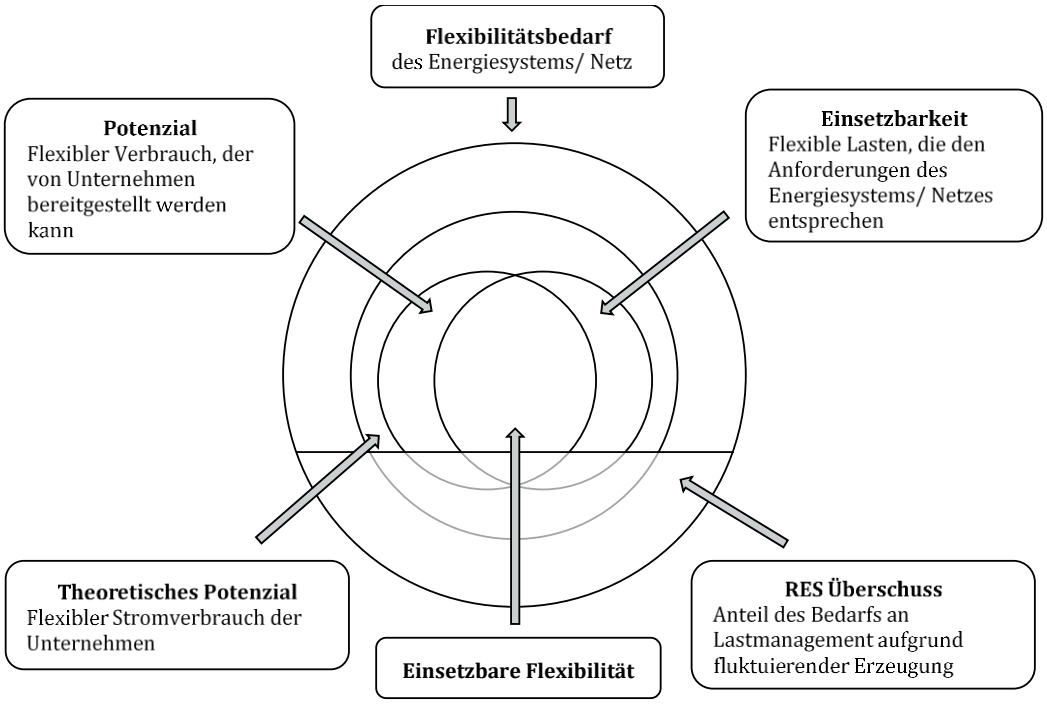
- Leicht zugängliche Informationen und Unterstützung in jeder Phase der Entscheidungsfindung, da in jeder Phase unterschiedliche Hindernisse und Herausforderungen auftreten;
- Strukturelle Merkmale des Unternehmens sowie wirtschaftliche, technische, verhaltens- und motivationsbedingte sowie externe und informationsbezogene Hemmnisse sind zu berücksichtigen;
- Die Umsetzung von Maßnahmen kann durch die folgenden Ansätze erleichtert werden:
    - Die Hemmschwellen für energiebezogene Maßnahmen sollten gesenkt werden: Audits, Energiemanagementsysteme und die Installation von Steuerungstechnologien für energieverbrauchende Geräte können als Türöffner fungieren;
    - Wenn ein Verantwortlicher für Energiefragen im Unternehmen verantwortlich ist und wenn Entscheidungen über Energiemaßnahmen intern getroffen werden können, verläuft der Entscheidungs- und Umsetzungsprozess in der Regel reibungsloser;
    - Bei der Entscheidungsfindung können ungünstige Rentabilitätskennzahlen wie kurze Amortisationszeiträume Maßnahmen behindern; langfristige und nicht-energetische Vorteile sollten ebenfalls in Betracht gezogen werden, um den Wert der Maßnahmen zu erhöhen;
    - Der Aufwand sollte für das Unternehmen gering gehalten werden:
        - ein Selbstbewertungsinstrument für die erste Überprüfung potenzieller Maßnahmen etablieren, die den Erwartungen und Merkmalen des Unternehmens entsprechen;
        - Dienstleistungen oder Komplettlösungen für die Identifizierung und Umsetzung von Maßnahmen anbieten.

2. Welche Unternehmen des Dienstleistungssektors sind Zielgruppen für Verbrauchsflexibilität und wie groß ist das Potenzial?

Das Potenzial im Dienstleistungssektor ist derzeit im Gegensatz zum industriellen Sektor noch weitgehend unangetastet. Neben den energieintensiven Unternehmen könnten diejenigen mit flexibel einsetzbaren Geräten, die nicht zum Kerngeschäft gehören (und daher bei Verwendung für DR-Zwecke weniger kritisch sind), für DR von besonderem Interesse sein. Aufgrund der homogenen Verteilung der Dienstleistungsunternehmen im ganzen Land könnte ihr Potenzial das regional konzentriertere Lastmanagement im Industriesektor ergänzen. Da der Dienstleistungssektor rund 30% des deutschen Strombedarfs ausmacht, könnte er für DR eine wichtige Rolle spielen und angesichts der fortschreitenden Entwicklung zur Dienstleistungswirtschaft sogar an Bedeutung gewinnen. Der erste Schritt zur Identifizierung von Zielgruppen im Dienstleistungssektor bestand darin, die Subsektoren mit den hohen Anteilen am Stromverbrauch auszuwählen, insbesondere die Subsektoren, in denen flexible Geräte einen hohen Anteil dieses Verbrauchs ausmachen. Die Subsektoren Büro, Handel und Gastgewerbe (Hotels/Restaurants) verursachen zusammen mehr als 50% des gesamten Stromverbrauchs des Sektors. Der Lebensmitteleinzel- und Großhandel sowie Hotels haben den höchsten Stromverbrauch pro Unternehmen, während Büros einen hohen Anteil am Stromverbrauch insgesamt haben, aber den geringsten Verbrauch pro Unternehmen im Vergleich zu den anderen Subsektoren. Geräte mit flexiblem Verbrauch sind Lüftung, Klimatisierung, Kühl- und Gefriergeräte sowie elektrische Warmwasserbereitung, Nachtspeicherheizungen und Wärmepumpen.

Bei der Schätzung der Flexibilitätspotenziale wurden verschiedene analytische Dimensionen berücksichtigt, die die theoretischen, technischen, wirtschaftlichen und praktischen Potenziale definieren. Die Verfügbarkeit flexibler Geräte bestimmt den flexiblen Energieverbrauch, d.h. das theoretische Potenzial; die technischen Einschränkungen bei der Flexibilisierung der Nachfrage beeinflussen das technische Potenzial. Diese technischen Einschränkungen äußern sich z.B. in der Dauer und Häufigkeit, mit der Geräte flexibel zugunsten von DR eingesetzt werden können, ohne deren Funktion negativ zu beeinflussen. Das praktische Potenzial ergibt sich durch die Bereitschaft zur Durchführung von DR. Neben den Potenzialen, die den verfügbaren flexiblen Verbrauch darstellen, wird auch die Einsatzfähigkeit dieser Potentiale berücksichtigt, d.h. das Timing und die Abstimmung von Verfügbarkeit und Flexibilitätsbedarf. Die Ergebnisse stammen aus Optimierungsmodellläufen (bei einem Anteil von 50% erneuerbaren Energien unter Verwendung von Erzeugungs- und Verbrauchsprofilen). Abbildung IX-1 zeigt den Zusammenhang zwischen den Konzepten von Flexibilitätsbedarf, -potenzial und -verfügbarkeit.

Abbildung IX-1: Darstellung des Flexibilitätsbedarf, Potenzial und Einsetzbarkeit
Die abgebildeten Größenverhältnisse der Konzepte stellen nicht die tatsächlichen Relationen dar



Restaurants und der (Lebensmittel-)Handel haben den höchsten Stromverbrauch bei flexiblen Geräten und damit das höchste theoretische Potenzial. Für die betrachteten Branchen verursachen die flexiblen Geräte Klima- und Kühlgeräte (Kühlschränke und Kühlräume) den höchsten Strombedarf. Es ist zu beachten, dass sich die Geräte auch dadurch unterscheiden, wie sie für verschiedene Zwecke eingesetzt werden können, z.B. Klimatisierung und Kälteprozesse haben beide hohe DR-Potenziale, aber Klimatisierung wird in vordefinierten Zeitspannen eingesetzt und die Kälteerzeugung wird kontinuierlich betrieben. Klimatisierung erwies sich aufgrund seines Lastprofils als am besten für die Anforderungen der RES-Integration geeignet, aber der Bedarf an Klimatisierung in bestimmten Zeitfenstern ist problematisch, wenn der automatisierte Einsatz von Flexibilität ohne zeitliche Einschränkung durchgeführt werden soll. Die Kühlung könnte leichter automatisch gesteuert werden, aber der Prozess ist im Allgemeinen kritischer als bei Klimatisierung.

Die Ergebnisse unserer Schätzungen sind in Tabelle IX-2 enthalten. Das theoretische Potenzial ist der Gesamtverbrauch von flexiblen Geräten in den genannten Sektoren und macht etwa 35% des gesamten Stromverbrauchs der Subsektoren aus. Das technische Potenzial variiert je nach Annahmen darüber, inwieweit die Geräte flexibel eingesetzt werden können (Szenarien A und B). Die technische Einsatzfähigkeit ist näher an Szenario B, d.h. die Akzeptanz einer stärkeren Nutzung der Geräte für DR-Zwecke ist eine stärkere Einschränkung der Einsatzfähigkeit der Flexibilität als der Flexibilitätsbedarf. Die

Flexibilität, mit der die Residuallast geglättet werden kann, wird auf 0,5 TWh geschätzt. Das praktische Potenzial und die praktische Einsetzbarkeit berücksichtigen nur die Unternehmen, die bereit sind, sich an DR zu beteiligen.

Es ist schwierig, das wirtschaftliche Potenzial abzuschätzen, da es derzeit nur wenige Möglichkeiten für den Dienstleistungssektor gibt, seine flexible Nachfrage zu vermarkten. Zukünftige Entwicklungen deuten auf eine Wertsteigerung hin, aber die Vermarktungsmöglichkeiten müssen noch ausgebaut werden. Der modellierte Einsatz von Flexibilität ist marktbasiert und wird durch modellierte Preissignale aus einem Spotmarkt errechnet. Dieser ergibt mögliche Gewinne von 23 €/MWh. Andere (vor allem netzbasierte) Anreizsysteme für flexibles Verhalten, wie beispielsweise variable Netztarife, könnten zukünftig ein höheres Erlöspotenzial aufweisen. Die Erlöse auf den Ausgleichsmärkten liegen heute bei etwa 400 - 700 €/ MWh, sind aber für den Dienstleistungssektor noch nicht zugänglich. Die von den Unternehmen zu erwartenden Zahlungen hängen von den Einzelheiten des Verfahrens zur Flexibilisierung der Geräte und den Merkmalen der Geräte ab, können aber in einer vergleichbaren Bandbreite von etwa 300 - 900 €/ MWh geschätzt werden.

Table IX-2: Zusammenfassung von Flexibilitätspotenzialen und Einsetzbarkeit

		Einheit	**VAC**	**RF**	**HW**	**HP**	**NSH**	**Gesamt**
Potential ("verfügbare" Flexibilität)	Theoretisches Potenzial (Stromverbrauch)	TWh	7.83	9.27	2.90	0.30	1.79	22.09
	Technisches Potenzial Szenario A	TWh	0.45	1.20	0.36	0.02	1.79	3.82
	Technisches Potenzial Szenario B	TWh	1.6	2.4	0.36	0.04	1.79	6.19
	Praktisches Potenzial (A)	TWh	0.14	0.43	0.08	<0.01	0.29	0.90
Einsetzbarkeit ("benötigte" Flexibilität)	Technische Einsetzbarkeit der Flexibilität	TWh	2.75	2.64	1.22	0.13	0.99	7.74
	Praktische Einsetzbarkeit der Flexibilität	TWh	0.65	0.64	0.30	0.03	0.20	1.82
	(Technische) Reduktion von RES Überschuss	TWh	0.18	0.14	0.01	0.07	0.10	0.51
	Erwarteter finanzieller Erlös	€/MWh	800/ 300	900	n/a	n/a	n/a	n/a

VAC: Lüftung und Klimatisierung, RF.: Kühlen und Gefrieren, HW: Warmwasserbereitung, HP: Wärmepumpen, NSH: Nachtspeicherheizungen
Scenario A: 1-2 hours flexible operation per appliance and day, Scenario B: doubled flexible operation (for details cp. Chapter V).
Die Zahlen sind teilweise aus den Originaldaten abgeleitet und finden sich in den Veröffentlichungen nicht im gleichen Detailgrad wieder.

3. Welche Determinanten beeinflussen das Flexibilitätspotenzial in Unternehmen des Dienstleistungssektors?

Wie bereits in der Einleitung erläutert, bilden insbesondere technische, organisatorische, wirtschaftliche, verhaltensbezogene und externe Determinanten die analytischen Dimensionen, um Einflussfaktoren auf den Einsatz von energiebezogenen Maßnahmen zu bewerten. Die Dimensionen sind teilweise miteinander verknüpft und können jeweils hemmende oder unterstützende Aspekte umfassen, die die Potenziale von Unternehmen zur Umsetzung von Maßnahmen beeinflussen (vgl. Abbildung IX-2). Die Kontrolle über diese Faktoren eröffnet die Möglichkeit, treibende Kräfte zu nutzen und Hemmnisse abzubauen, um die DR-Potenziale voll auszuschöpfen.

Die folgenden Aspekte wurden als relevant identifiziert, um die Nachfrage in Unternehmen (flexibler) zu gestalten:

- **Verhaltensdimension** - Einstellung und Motivation der beteiligten Personen
    - Positive Einstellung zu Maßnahmen: Die Überzeugung, dass die Maßnahmen ein wichtiger Beitrag zur Energiewende sind, hat sich als wichtiger Treiber für die Umsetzung energiebezogener Maßnahmen erwiesen.
    - Positive Imageeffekte auf den Kunden: Gerade in Branchen, die eine enge Beziehung zu ihren Kunden haben, kann ein positives Image ein Verkaufsargument für energiebezogene Maßnahmen sein, die das Unternehmen von der Konkurrenz abheben können.
    - Priorität von Energiefragen/ Management ist überzeugt: Dieser Aspekt ist oft Voraussetzung für die Auseinandersetzung mit möglichen Maßnahmen. Die Priorität ist höher, wenn Energiemaßnahmen als strategisch angesehen werden, und ist in der Regel niedrig, wenn die Energiekosten niedrig sind und nur kleine Potenziale erwartet werden.
    - Komfort: Die Maßnahmen sollten den Komfort der Mitarbeiter oder Kunden nicht beeinträchtigen, da sonst die Qualität der Arbeit oder der Dienstleistung(en) leiden könnte. Dieser Aspekt steht in engem Zusammenhang mit der organisatorischen Dimension, z.B. Arbeitsprozesse, Geschäftszeiten und Betrieb von flexiblen Geräten.

- **Technische Dimension** - verfügbare flexible Geräte, Einschränkungen hinsichtlich ihres Betriebs und unterstützende Technologien
    - Eignung: die Verfügbarkeit von Geräten, die flexibel betrieben werden können. Dieser Aspekt betrifft organisatorische Fragen, die die Verfügbarkeit von branchen- und größentypischen Geräten und die Besonderheiten ihres Betriebs betreffen.
    - Merkmale des Gerätes: Die Merkmale beeinflussen die Bereitschaft der Unternehmen, das jeweilige Gerät für DR zu nutzen, z.B. wenn die Nutzung

des Gerätes einen Dauerbetrieb erfordert oder wenn die Funktion durch Ein- und Ausschalten leiden könnte. Daher ist die Verwendung von AC für DR in der Regel eher akzeptiert als für Gefriergeräte. Andererseits ist der Betrieb von AC kein kontinuierlicher Prozess, d.h. er ist empfindlicher gegenüber Störungen, da er nur in vordefinierten Zeitfenstern benötigt wird. Kann der flexible Betrieb eines solchen Gerätes nicht vorhergesagt oder beeinflusst werden, verringert sich die Akzeptanz der Verwendung für DR-Zwecke. Der übliche Betrieb eines Gerätes bestimmt auch den möglichen Wert seiner Flexibilität, z.B. wenn das Gerät dann flexibel verfügbar ist, wenn Flexibilität im System benötigt wird.

- Energiemanagementsysteme/ Gebäudeleittechnik oder Steuergeräte: Diese Unterstützungstechnologien erleichtern die Identifizierung von Maßnahmen, die Steuerung von Geräten und senken die Initiierungskosten und den Aufwand.

- **Organisatorische Dimension** - interne Prozesse, Verantwortlichkeiten und Arbeitsprozesse
  - Unternehmensmerkmale: Größe und Branche eines Unternehmens bestimmen Energieintensität, Kerngeschäft, verfügbare Geräte und ob es Verantwortliche für Energiefragen gibt.
  - Entscheidungsprozesse: Ein Energiemanager, der die Verantwortung für die Förderung energiebezogener Maßnahmen übernimmt, ist in der Regel für die Umsetzung von Vorteil. Ist das Unternehmen nicht befugt, Entscheidungen allein zu treffen (z.B. weil es Teil einer Muttergesellschaft ist oder die Geräte nicht besitzt), kann die Umsetzung von Maßnahmen behindert werden. Im Falle von Unternehmensketten kann die zentralisierte Entscheidungsfindung den Roll-out erleichtern und beschleunigen. Für die Aggregation von Lasten und die Senkung der Transaktionskosten könnte dies von besonderem Interesse sein.
  - Arbeitsprozesse: Der flexible Einsatz von Geräten birgt das Risiko von Prozessstörungen. Im Dienstleistungssektor ist dies ein geringeres Hemmnis als in Industrieunternehmen, da die flexiblen Geräte in der Regel nicht zum Kerngeschäft gehören. Dennoch kann der Betrieb von Geräten mit Arbeitsprozessen oder Gewohnheiten von Mitarbeitern/Kunden interagieren.
  - Aufwand: Ein hoher organisatorischer Aufwand verringert in der Regel die Absicht, Maßnahmen zu ergreifen und ist mit Kosten verbunden. Der Aufwand zur Nutzung der flexiblen Potenziale eines Unternehmens steht im Zusammenhang mit technischen (z.B. Verfügbarkeit von Steuerungstechnologien), organisatorischen (Energieverantwortliche) und motivationalen (z.B. Bereitschaft und Priorisierung) Aspekten.

- Energieintensität/-verbrauch: In Unternehmen mit geringer Energieintensität ist der Anteil der Energiekosten in der Regel gering und ebenso die Relevanz von Energiethemen. Dieser Aspekt steht in Wechselwirkung mit Motivationsaspekten zur Umsetzung von Maßnahmen.
- Erfahrung: Erfahrungen mit anderen energiebezogenen Maßnahmen können das Wissen über den Energieverbrauch erweitern und die Identifizierung von Potenzialen und die kompetente Auswahl von Maßnahmen erleichtern.

- **Wirtschaftliche Dimension** - finanzielle Aspekte der Rentabilität und der Kosten
  - Rentabilität: Die Rentabilität ist abhängig von den Rahmenbedingungen (z.B. Regulierung und Marktzugang). Die Rentabilität wird durch die folgenden Faktoren beeinflusst:
    - Maßnahmen/notwendige Geräte sind zu teuer oder nicht finanzierbar,
    - Energiekosten,
    - schlechte Beurteilung der Rentabilität,
    - erwarteter Gewinn im Verhältnis zum Aufwand/ Risiko,
    - geringer Wert der Flexibilität/ Mangel an (regulatorischen) Anreizen (z.B. wenn ein konstanter Konsum belohnt wird).

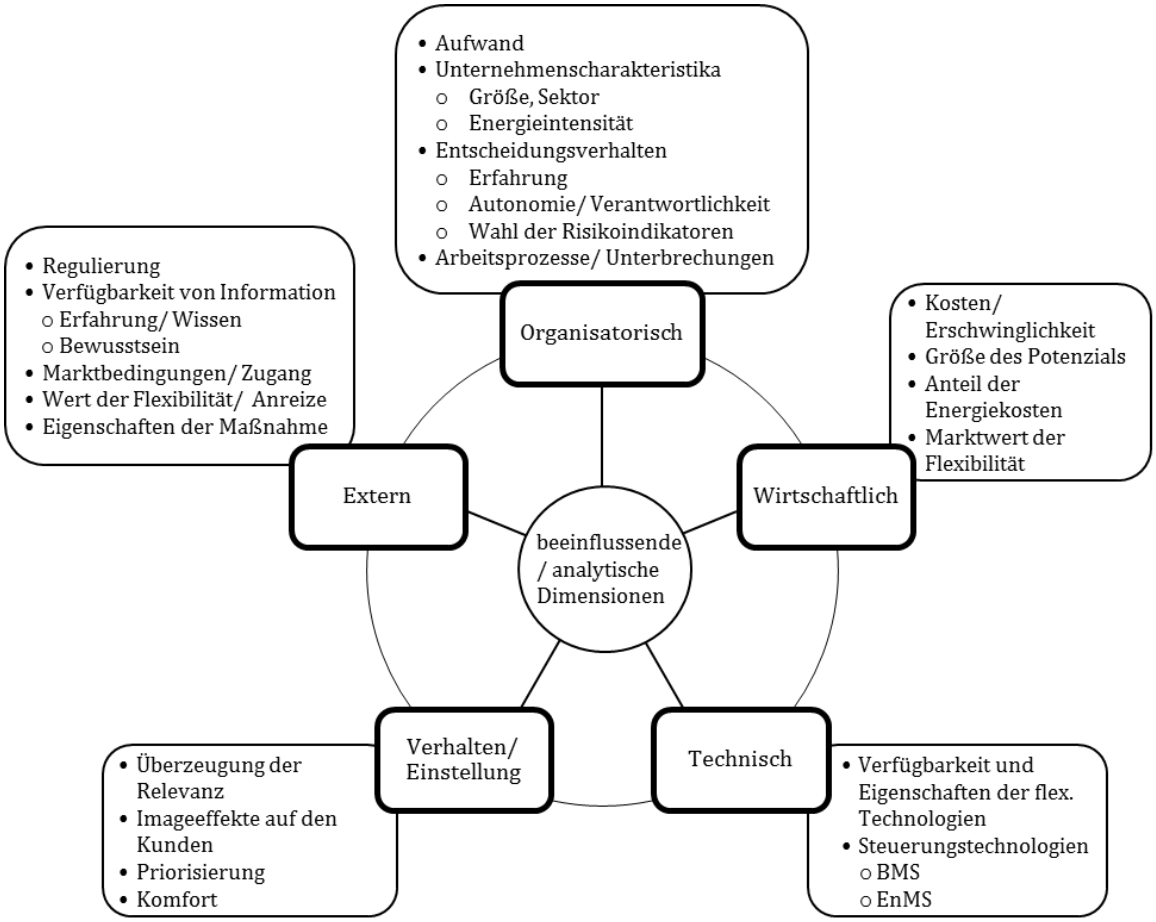
- **Externe Dimension** - Gegebenheiten, regulatorischer Rahmen und Markt-bedingungen
  - Regulierung: Wenn der regulatorische Rahmen unklar ist oder gar die Teilnahme an den Märkten erschwert und erschwert, wird DR nicht in Betracht gezogen. Eine Regulierung ohne Anreize senkt auch die Rentabilität von Maßnahmen.
  - Marktzugang: Die Teilnahme am Regelenergiemarkt ist gerade für kleine Energieverbraucher kompliziert oder kaum möglich.
  - Informationen: Die Verfügbarkeit von Informationen wird durch den Entwicklungsstand des Marktes und die Standardisierung der Prozesse oder die Zugänglichkeit der Märkte beeinflusst, insbesondere wenn die Bereitstellung von Informationen viel Aufwand erfordert und wenn wenig Erfahrung vorhanden ist. Im Gegensatz zu Energieeffizienz-Audits gibt es keine vergleichbaren systematischen Informationen über Flexibilitätspotenziale für Unternehmen.
  - Bewusstsein: Das Bewusstsein ist eng mit der Verfügbarkeit von Informationen und der Motivation und Erfahrung eines Unternehmens in Energiefragen verbunden. DR ist im Dienstleistungssektor nicht üblich und

fast 50% der Unternehmen haben noch nichts davon gehört. Dadurch wird es schwieriger, das Potenzial zu erschließen.

- Spezifikationen der Maßnahme: Spezifikationen beeinflussen die Akzeptanz der Flexibilisierung der Nachfrage und beziehen sich auf die Geräte- und Unternehmensmerkmale, sind aber auch Bestandteil des Vertrages mit einem Dienstleister. Wenn z.B. der Betrieb eines Geräts für DR-Zwecke keine nennenswerten Auswirkungen hat oder vorhersehbar ist, wird ein Unternehmen die Maßnahme eher ergreifen.

Die Ergebnisse zeigten, dass verschiedene Entscheidungsphasen die Relevanz und die Einstufung der Hemmnisse beeinflussen. Für die praktische Umsetzung sind insbesondere technische und wirtschaftliche Aspekte und Auswirkungen auf Arbeitsprozesse relevant, während verhaltensbezogene und organisatorische Aspekte die Priorisierung der DR beeinflussen, d.h. wenn das Unternehmen an der Auseinandersetzung mit den Maßnahmen interessiert ist.

Abbildung IX-2: Einflussfaktoren auf Maßnahmen zur Flexibilisierung des Energieverbrauchs (DR)

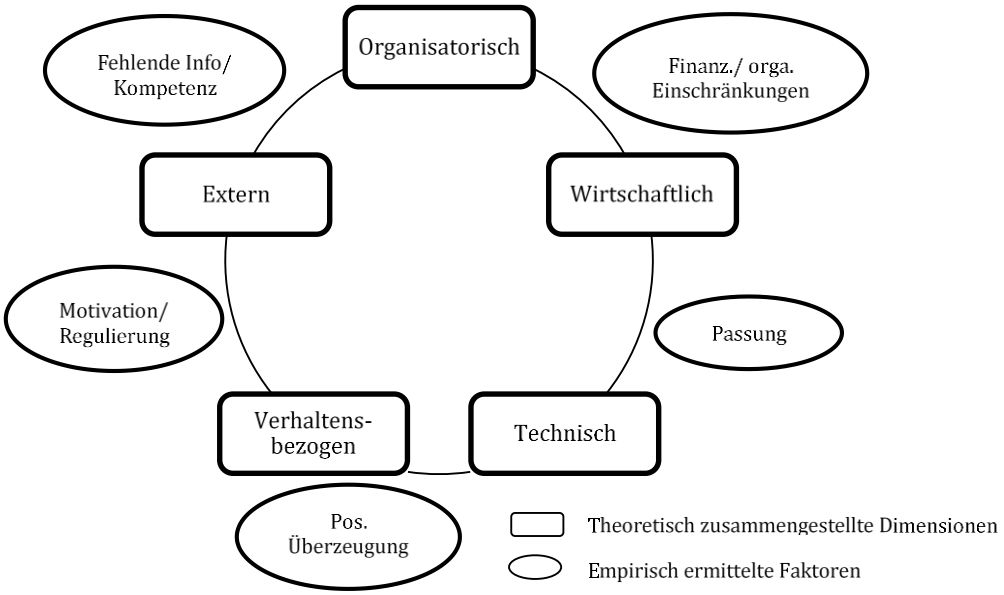


4. Wie können wir Synergien zwischen Verbrauchsflexibilität und Energieeffizienz nutzen?

Sowohl die Energieeffizienz als auch die Verbrauchsflexibilität gehören zu den tragenden Säulen der Energiewende und verfolgen das gleiche Ziel. Für Unternehmen erfordern beide eine Veränderung des Verbrauchsverhaltens. Während Energieeffizienz eine Reduzierung des Verbrauchs oder eine Steigerung der Produktivität bedeutet, bedeutet Verbrauchsflexibilität eine Änderung des Verbrauchsmusters durch Senkung oder Erhöhung des Verbrauchs in Abhängigkeit von der Stromerzeugung oder -volatilität. So können sich die Konzepte im konkreten Fall gegenseitig entgegenwirken, z.B. wenn der Verbrauch auf ein Minimum reduziert wird, wird auch das Flexibilitätspotenzial reduziert. Wenn Prozesse am effizientesten ablaufen, kann die Flexibilisierung des Verbrauchs die Effizienz der Prozesse beeinträchtigen. Welches Konzept hinsichtlich der Effizienz des Energiesystems günstiger ist, hängt von der Energieerzeugungs- und Netzstabilitätssituation ab, z.B. bei einem Überschuss an erneuerbaren Energiequellen ist die Verlagerung der Nachfrage auf diese Zeiten mehr wert als Energieeinsparungen und bei Netzinstabilität kann die Nichtnutzung verfügbarer Energie sogar günstig sein. Folglich hängt der Wert der Energieeffizienz und/oder der Verbrauchsflexibilität vom Zeitpunkt ab. Während sich Energieeinsparungen oder Effizienz durch Kostensenkungen auszahlen, müssen für die Verbrauchsflexibilität externe Anreize geschaffen werden. Dennoch ist es vorteilhaft, wenn man es den Unternehmen ermöglicht, beides umzusetzen.

Die Annahme, dass EE und DR mit vergleichbaren Treibern und Hemmnissen konfrontiert sind, konnte bestätigt werden, wenn diese auch im konkreten Fall unterschiedlich sind. Im Vergleich zur verallgemeinerten Taxonomie liegen die empirisch bewerteten Faktoren (vgl. Kapitel VIII) diagonal zu den theoretisch zusammengestellten (vgl. Kapitel I) und spiegeln den Zusammenhang zwischen den Dimensionen wider. Sie zeigen jedoch den gleichen Schwerpunkt, und einige dieser Faktoren beeinflussen auch die Umsetzung von Maßnahmen in vergleichbarer Weise (Abbildung IX-3).

Abbildung IX-3: Empirische Bestätigung der analytischen Dimensionen energiebezogener Maßnahmen



Es ist daher naheliegend, die Erfahrungen mit EE zur Förderung von DR zu nutzen, zumal Flexibilitätspotenziale bisher selten genutzt werden und entsprechende Politiken und Regulierung noch nicht weit entwickelt sind. Einige erfolgreiche Politikinstrumente könnten erweitert oder übertragen werden, um auch DR abzudecken. So haben beispielsweise Energieeffizienzaudits (informationspolitisches Instrument) einen wesentlichen Einfluss auf die Umsetzung von Energieeffizienzmaßnahmen. Wenn eine Bewertung der Flexibilitätspotenziale in die Audits einbezogen würde, könnte auch DR unterstützt werden. Gleiches gilt für Energieeffizienznetzwerke (Weiterbildung/ Training), die auch als DR-Netzwerke funktionieren könnten, möglicherweise mit der Option, Partner zur Lastaggregation innerhalb der Netzwerke zu finden. Fonds oder Subventionen (finanzpolitische Instrumente) können dazu beitragen, Einschränkungen durch Investitionskosten für notwendige Technologien, wie z.B. Energiemanagementsysteme oder Gebäudemanagement, zu beseitigen. Diese unterstützenden Technologien erhöhen auch den „Intelligenzindikator“ des Gebäudes (vgl. EPBD) und könnten mit Kennzeichnungsnormen für intelligente Technologien (Informationsverordnung) gefördert werden. Die Verwendung eines Labels zur Erhöhung der Sichtbarkeit von Maßnahmen könnte auch die Imageeffekte verbessern und als Treiber fungieren. Eine detailliertere Bewertung der übertragbaren politischen Maßnahmen findet sich in Kapitel VIII. Die allgemeinen Regulierungsinstrumente in Bezug auf Vermarktungsmöglichkeiten der Verbrauchsflexibilität und des Marktzugangs müssen noch verbessert werden und interagieren mit einer Neugestaltung der Märkte, z.B. der Einführung neuer Akteure und Dienstleister. Zu Beginn der Einführung der Nutzung von DR-Potenzialen kommen vergleichbare Zielgruppen wie bei EE ins Spiel - Unternehmen mit hohem Energieverbrauch

und bereits verfügbaren Steuerungstechnologien, die über ihren Energieverbrauch und die Laufzeiten ihrer Geräte bestens informiert sind. Somit kann EE zum Türöffner für DR werden.

3.3 Schlussfolgerungen und Empfehlungen

Diese Arbeit untersucht Erfolgsstrategien für die Umsetzung von energiebezogenen Maßnahmen (Energieeffizienz und Verbrauchsflexibilität), sowie Einflussfaktoren auf das Potenzial zur Umsetzung dieser Maßnahmen. Es werden Zielgruppen identifiziert und eine breite und detaillierte Bewertung der theoretischen, technischen, wirtschaftlichen und praktischen Potenziale der Verbrauchsflexibilität im Dienstleistungssektor vorgestellt. Um die Potenziale zu nutzen, werden auf der Grundlage dieser Ergebnisse politische Empfehlungen abgeleitet, um sowohl die Energieeffizienz als auch die Verbrauchsflexibilität zu verbessern.

3.3.1 Schlussfolgerungen

Einflussfaktoren

In allen Phasen der Entscheidungsfindung, von der Identifizierung geeigneter Maßnahmen bis zur praktischen Umsetzung, müssen verschiedene Einflussfaktoren auf die Umsetzung von Maßnahmen berücksichtigt werden. Die Taxonomie der Hemmnisse für die Energieeffizienz wurde in dieser Arbeit bestätigt und erfolgreich auf die Verbrauchsflexibilität übertragen. Darüber hinaus wurden Einstellungsaspekte mit signifikantem Einfluss identifiziert, die die bestehenden Dimensionen der Taxonomie ergänzen können, und es wird eine neue und allgemeinere Taxonomie für energiebezogene Maßnahmen vorgeschlagen.

Die Bewertung von Einflussfaktoren und deren Auswirkungen auf die Umsetzungsabsicht zeigte, dass zwischen Hemmnissen mit hoher Bewertung (mit Angabe ihres Auftretens) und der Relevanz von Einflussfaktoren (mit Angabe der Stärke ihrer Wirkung auf die Absicht oder Umsetzung von Maßnahmen) zu unterscheiden ist. Die identifizierten analytischen Dimensionen umfassen die wichtigen Einflussfaktoren für energiebezogene Maßnahmen in Unternehmen. Die Potenziale energiebezogener Maßnahmen verändern sich durch die Einflussfaktoren. Auch die Relevanz dieser Faktoren unterscheidet sich, z.B. je nach Unternehmenstyp, Art der Maßnahme/ Technologie oder Entscheidungsphase. Diese Ergebnisse können dabei helfen, Maßnahmen und Zielgruppen besser aufeinander abzustimmen und unterstützende Instrumente für eine erfolgreiche Umsetzung zu entwickeln.

Potenziale

Verschiedene Arten von Potenzialen sind zu unterscheiden. In dieser Arbeit wird das theoretische, technische und praktische Potenzial auf der Ebene der Subsektoren des Dienstleistungssektors und der Querschnittstechnologien vorgestellt. Wie bereits erwähnt, ist der Marktzugang und andere Möglichkeiten zur finanziellen Nutzung der Flexibilitätspotenziale für Unternehmen mit kleinen Lasten eingeschränkt. Ein Szenario zur Beurteilung der wirtschaftlichen Potenziale bzw. der erwarteten Zahlungen bleibt somit hypothetisch. Das in Kapitel VII verwendete Choice-Experiment ist eine Methode, bei der ein Fall der Teilnahme an DR so konkret wie möglich beschrieben wird, damit die gegebenen Antworten möglichst realistisch sind. Dennoch können die Ergebnisse nur bedingt verallgemeinert werden. Aufgrund der geringen Erfahrung der Unternehmen in diesem Bereich und unklarer regulatorischer Aspekte sind die geschätzten erwarteten Zahlungen nur indikativ. Die erwarteten Zahlungen hängen deutlicher von der Vorhersagbarkeit ab als von der Dauer oder Häufigkeit einer Intervention für DR-Zwecke und unterscheiden sich zwischen den Geräten.

Unsere Methoden zur Abschätzung der theoretischen und technischen Potenziale und ihrer Einsetzbarkeit umfassen Bottom-up-Berechnungen auf der Grundlage empirisch erhobener Verbrauchsdaten und der Verfügbarkeit von Geräten bzw. Optimierungsmodellierungen. Diese Schätzungen führten dazu, dass 17-25% des flexiblen Stromverbrauchs von den Unternehmen für DR (technisches Potenzial) bereitgestellt und etwa 35% technisch eingesetzt werden könnten. Das geringere technische Potenzial ist durch die vorsichtigen Annahmen bedingt, inwieweit ein Gerät für DR-Zwecke eingesetzt werden kann, ohne seine Funktionalität zu beeinträchtigen oder zu verlieren. Der Modellierungsansatz führte zu einer höheren technischen Einsetzbarkeit, was auf höhere Potenziale hindeutet, wenn diese technischen Möglichkeiten und Aspekte von Komfort und Akzeptanz stärker strapaziert würden. Unter diesem Gesichtspunkt verschwimmen die Grenzen zwischen dem technischen und dem praktischen Potenzial und die Konzepte können nicht unabhängig voneinander betrachtet werden.

Praktische Umsetzung

Obwohl DR in den weniger energieintensiven Sektoren selten ist, muss das Rad nicht neu erfunden werden, um Wege zur Förderung der Verbrauchsflexibilität zu finden. Viele erfolgreiche Politikmaßnahmen können aus der EE-Politik übernommen werden oder dienen bereits sowohl der EE als auch DR. Für eine wirksame Politik müssen sich die Rahmenbedingungen (einschließlich der damit verbundenen Regulierung) ändern, um DR attraktiver zu machen. Es ist davon auszugehen, dass die Relevanz mit zunehmendem Anteil erneuerbarer Energien zunehmen wird; durch die Förderung von Steuerungstechnologien, Managementsystemen und Automatisierung können bereits Eckpfeiler gesetzt werden. Im Vergleich zu den größeren Potenzialen pro Unternehmen in den energieintensiven

Sektoren könnten die weniger energieintensiven, aber regional verteilten Unternehmen ihre Flexibilität auf der Ebene der Verteilnetze nutzen.

Ob ein Unternehmen, eine Anlage oder ein Prozess besser für EE- oder DR-Maßnahmen geeignet ist, hängt von einer Vielzahl von Faktoren ab: Hohe Lasten und Verbräuche deuten auf ein hohes Potenzial für beide hin, aber die Einsetzbarkeit wird durch Unternehmens- und Technologiemerkmale bestimmt. Diese Determinanten lassen sich für EE und DR gleichermaßen beschreiben. Ein energieintensiver Prozess, der zu einem bestimmten Zeitpunkt benötigt wird, unvorhersehbar ist oder nicht unterbrochen werden kann, ist für DR nicht geeignet, kann es aber für EE sein. Während die Effizienz eines Prozesses durch den Einsatz effizienterer Technologien verbessert werden kann, ist DR spezifischer und erfordert Änderungen der Prozesse selbst. Daraus folgt, dass bei der Potenzialabschätzung die unterschiedliche Eignung von Geräten für DR oder EE berücksichtigt werden muss.

3.3.2 Ausblick und Empfehlungen

Die theoretische Taxonomie und Klassifizierung von Hemmnissen ist weithin anerkannt und bestätigt, mit Methoden, die mit denen in dieser Arbeit vergleichbar sind. Um Details dieser Einflussfaktoren auf die Entscheidungsfindung und Umsetzung energiepolitischer Maßnahmen zuverlässig zu ermitteln, bedarf es guter Bewertungsinstrumente. Die Faktoranalyse zur Bestimmung der wichtigsten Einflussfaktoren führte zu zufriedenstellenden Kategorien. Je nach Kontext ist es allerdings schwierig, die Faktoren eindeutig den verschiedenen Dimensionen zuzuordnen. Die zukünftige Forschung könnte sich auf die Entwicklung von Instrumenten zur systematischen Bewertung der wichtigsten analytischen Dimensionen für energiebezogene Maßnahmen konzentrieren. Mit Methoden der Testtheorie und der Item-Konstruktion können klare und standardisierte Skalen mit hohen Gütekriterien für Validität und Reliabilität entwickelt werden.

Die Ergebnisse dieser Arbeit stellen die Beziehung zwischen Einflussfaktoren auf das Potenzial bzw. deren Relevanz und Unternehmensmerkmalen, Maßnahmen und Entscheidungsphasen her. Studien, die sich mit Potenzialen in energiebezogenen Maßnahmen und deren Umsetzung befassen, sollten immer einen ganzheitlichen Ansatz unter Berücksichtigung all dieser Dimensionen verfolgen. Die in dieser Arbeit vorgeschlagene Kategorisierung kann dazu beitragen, die Bewertung von Potenzialen auf diese Weise zu verbessern und bildet die Grundlage für die Entwicklung von standardisierten Skalen.

Die Verbindung zwischen dem technischen und dem praktischen Potenzial impliziert, dass z.B. Steuerungstechnologien dazu beitragen können, die technischen Potenziale zu maximieren, indem sie die Chancen der technischen Möglichkeiten vollständig nutzen und mit diesen Lösungen ein größeres praktisches Potenzial erschließen, ohne die Bereitschaft zur Nutzung des Potenzials zu verlieren, d.h. die Potenziale steigen und die Differenz zwischen dem technischen und dem praktischen Potenzial wird geringer. Das maximale

Potenzial kann genutzt werden, wenn mehr Details über die Akzeptanz bestimmter Maßnahmen bekannt sind. Die allgemeine Bereitschaft zur Teilnahme an DR ist entscheidend, aber die Akzeptanz einer bestimmten Maßnahme hängt auch von Details wie der jeweiligen Technologie, den Unternehmensmerkmalen und der konkreten Umsetzung (z.B. Vorhersehbarkeit der Maßnahme) ab. Die erwarteten finanziellen Erlöse sind höher, wenn die Maßnahmen von Unannehmlichkeiten oder Nachteilen begleitet werden. Eine genauere Bestimmung des wirtschaftlichen Potenzials hängt daher auch von Anreizen ab, z.B. der Entwicklung von Geschäftsmodellen, Regulierungen und der besonderen Gestaltung von Maßnahmen und bedarf weiterer Forschung.

Glücklicherweise kann die Bereitschaft erhöht werden, indem man günstige Bedingungen gestaltet und die Ergebnisse über den Zusammenhang zwischen Einflussfaktoren und Bereitschaft nutzt. Die in dieser Arbeit getroffenen Annahmen zur Abschätzung der technischen Flexibilitätspotenziale und der Einsatzfähigkeit basieren auf anderer Literatur, sind aber nicht unbedingt aus der Praxis abgeleitet. Daher muss der Kompromiss zwischen der bestmöglichen Nutzung der Flexibilität einerseits und der Aufrechterhaltung eines akzeptablen Niveaus an Routine und Komfort andererseits ermittelt werden. Feldstudien können verschiedene Szenarien untersuchen, um mehr Erfahrung zu sammeln und die praktischen Potenziale durch realistische Messungen in den identifizierten Zielgruppen besser zu ermitteln.

Wenn energiebezogene Maßnahmen in Unternehmen betrachtet werden, ist es besonders in weniger energieintensiven Unternehmen hinderlich, dass Energie nicht zum Kerngeschäft gehört. Damit Maßnahmen umgesetzt werden können, muss ein strategischer Mehrwert geschaffen werden. Während viel über die Hemmnisse für solche Maßnahmen geforscht wird, muss eine erfolgreiche Umsetzung potenzielle Vorteile hervorheben, z.B. eine verbesserte Steuerbarkeit der Geräte und damit verbundener erhöhter Komfort und die Möglichkeit, das Image des Unternehmens in den Augen seiner Kunden zu verbessern. Letzteres wurde im Dienstleistungssektor als relevant erachtet, ebenso wie die Einstellung zu Maßnahmen und deren wahrgenommene Relevanz für die Energiewende. Diese nicht-energiebezogenen Vorteile könnten von Bedeutung sein, insbesondere wenn die wirtschaftlichen Anreize gering sind.

Bei der Entscheidung für eine bestimmte energiebezogene Maßnahme hängt es von der Netz- und Versorgungssituation ab, ob EE oder DR mehr wert ist. Darüber hinaus können sich verschiedene netzgetriebene oder marktgetriebene Situationen gegenseitig entgegenwirken, z.B. wenn es um Verbrauchsflexibilität zur Gewährleistung der Netzstabilität oder die Integration erneuerbarer Energien geht. Um auf diese Situationen angemessen reagieren zu können, muss ein einheitliches Anreizinstrument für die Marktteilnehmer entwickelt werden, z.B. ein variabler Tarif, der bereits die spezifische Situation berücksichtigt und damit eine Priorisierung der Systemanforderungen durch Anreize für die bevorzugte Nachfrageantwort impliziert. Dies wiederum erfordert Klarheit über die Prioritäten und eine Harmonisierung der Regulierung.

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Curriculum Vitae

Katharina Wohlfarth studied at the faculty of economics and behavioural sciences (Dipl.-Psych.) at the University of Freiburg with additional subjects in business economics, mathematics and physics. She wrote her diploma thesis in the research company Energy and Communication Technologies (EnCT GmbH) about energy efficiency by smart metering, where she afterwards worked as market researcher on new energy products and services, efficiency programs and intelligent energy measurement. In 2011, she took over responsibility for the working group of market research and evaluation studies.
She joined the Fraunhofer Institute for Systems and Innovation Research ISI/ Karlsruhe in 2013 with a research focus on evaluation of field studies, acceptance and effects of technologies as well as potentials of demand response and energy efficiency. The latter also became the focus of her doctorate thesis in 2016 under the guidance of Ernst Worrel from Utrecht University and Wolfgang Eichhammer from Fraunhofer ISI/ Utrecht University.

Energy efficiency and demand flexibility are two key strategies to meet the challenges of the energy transition. The companies' high share of total energy consumption suggests that these can make a contribution, but their potentials are still far from being exhausted. This study uses an interdisciplinary approach, taking the analytical dimensions of organisational, technical, behavioural, economic and external factors into account to identify target groups, success factors and potentials of energy efficiency and flexibility. Among the key achievements is an estimation of demand response potentials in the service sector. The combination of different methods allows for the assessment of the deployable flexibility and the improvement of a modelling approach with empirical survey data including the companies' willingness to participate in demand response. The study has resulted in a comprehensive set of influencing factors on demand flexibility, comparable to existing typologies for barriers and drivers to energy efficiency. An analysis of established energy efficiency policies showed possibilities for transferring these to demand response and may thus lead to synergies of the two.

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