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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 utilisation 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 EE 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., 2015b). 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 (Boβmann 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

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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, the focus is on German companies in the service sector, including both energy efficiency and demand response. This sector is 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, 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 (Weiβbach, 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 (Eβer 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 (Weiβbach, 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. The data is taken 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., 2015a). The total maximum load of the service sector can be estimated to 10 GW (Klobasa, 2007). Quotas concerning size and subsector were applied 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 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).

Statistical methods are used 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, logistic regression analyses are applied 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)).

Table 1
Structure of our sample.

Subsectors and numbers of companies ⇩	Size ⇨	small (1–9 employees)	medium (10–49 employees)	large (50 and more employees)	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**

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

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, a set of company characteristics expected to affect implementation of EE or DR measures was identified to evaluate the importance (Wohlfarth et al., 2018a, 2018b; Trianni and Cagno, 2012; DeCanio, 1998). These characteristics include 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):

- size of the company (i.e. dichotomized to less or more than 50 employees)
- affiliation to sector (as 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, a set of barriers suitable for EE and DR on that basis was compiled (see section 3.4). Considering DR and EE both as energy consumption related measures, the aim is to find 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. A list of general statements (including drivers and barriers, rated on a 5-point Likert-scale) was selected to compose 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. The authors 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 2 shows that about 50% of the surveyed companies have conducted some kind of EE measures within the last five years (i.e. since 2012). 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 2).

Table 2 below shows the share of companies that conducts 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.

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 (Fig. 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%. The data revealed differences between subsectors and sizes (Table 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

Table 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%

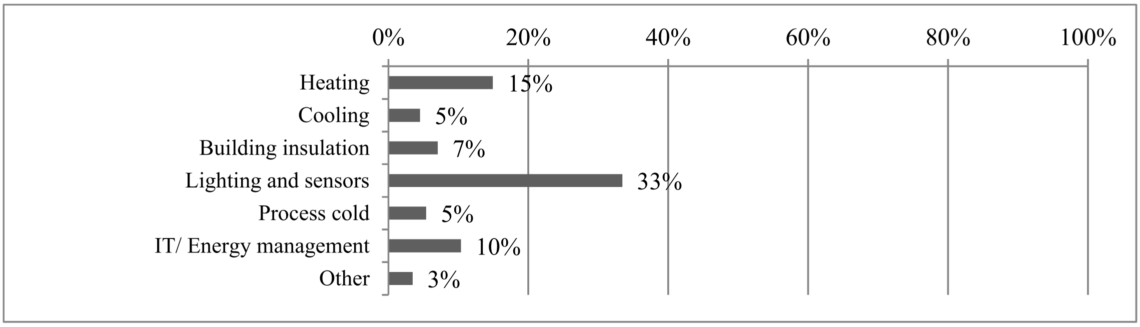

Fig. 1. Typical EE measures in companies of the service sector (n = 781, equals 48% of the surveyed companies).

(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).

Most of the companies conducting DR mentioned load shedding, followed by flexible tariffs or optimised purchasing of electricity (Fig. 2) as DR activities. The service sector has hardly entered the balancing markets. The shares differ between subsectors and sizes (Table 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%).

Table 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%

3.2. *Company characteristics influencing the implementation of EE and DR*

Table 3 shows the frequencies of the influencing factors (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.

Binary logit regression models are used to investigate on the influencing factors for planned or already implemented EE or DR (Table 4). Each model (EE and DR measures) is significant with a large effect ("f" in Table 4, cp. Cohen, 1988, 1992). Using a BMS, EnMS and profitability calculations can increase the probability that a company conducts 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. Regarding structural aspects (i. e. size, sector), 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

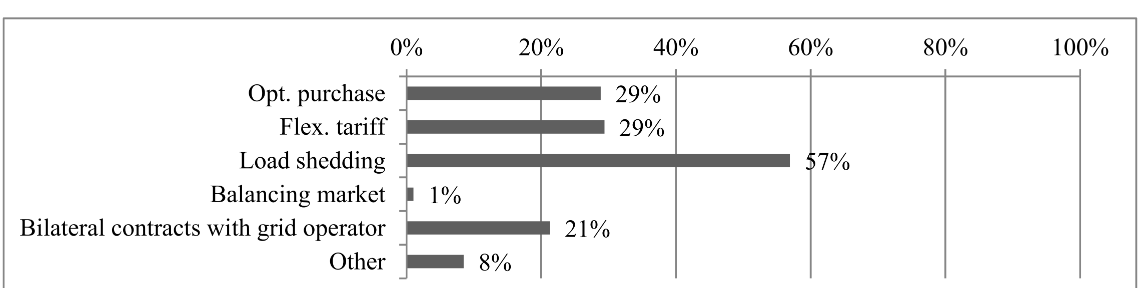

Fig. 2. Typical DR measures in companies of the service sector (n = 55, equals 4% of the surveyed companies).

Table 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.

(often a focus of audits).

Regarding the role of audits for EE, a weighted share of 22% of the surveyed companies have conducted an audit (Table 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 EE and DR

Based on the findings of drivers and barriers to EE, a set of statements representing drivers or barriers for EE measures as well as DR measures was introduced to the participating companies (Fig. 3). A ranking of the statements shows that the four highest ranked statements are the same for EE and DR measures (Fig. 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.

The comparison of EE and DR aims to determine the main factors affecting EE as well as DR (Table 5). A factor analysis is used to reveal the main categories for DR and EE, i.e. condensing the set of statements

Table 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
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
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) = 0.813, Bartlett's test on sphericity: $Chi^2(153)$ = 4981.35***; DR: KMO = 0.805, Bartlett's test on sphericity: $Chi^2(153)$ = 3362.50***Varimax rotation and Kaiser criterion used.Unassigned variables: Market offers – for EE below 0.5 and cross-loading for DR on unsuitability as well as on missing information.

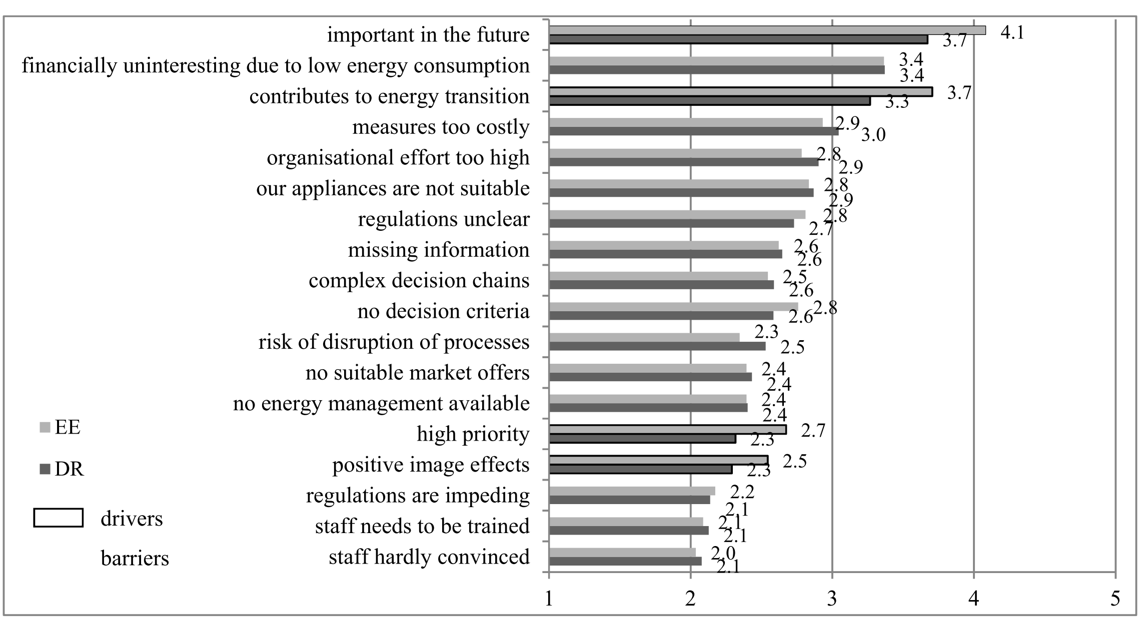

Fig. 3. Comparison of barriers towards EE and DR – overall comparison for weighted means.

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 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. Another regression analysis is used to evaluate this influence and the differences regarding EE and DR (Table 6).

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% for EE vs. 40% for DR), 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. This relation did not appear for DR. Assumedly, 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.

3.4. 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, existing EE regulations and policies need to be evaluated.

Different approaches to categorize policy instruments exist. Based on the categorization of UNFCCC (United Nations Framework Convention on Climate Change, 2000), the following categories are distinguished:

- 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 7 shows the general types and examples for policy instruments relevant for EE in companies.

The identification of types of German instruments for energy efficiency that apply to companies is based on the compilation of European energy efficiency policies of the MURE (Mesures d'Utilisation Rationnelle de l'Energie) database (Odyssee-Mure, 2018). The instruments listed in Table 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 8 shows the categorized energy efficiency policy instruments where also the general/cross-cutting instruments and those for appliances or buildings specifically are differentiated. Below the authors discuss how these instruments can be adapted to enhance the uptake of DR.

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:

Table 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

Table 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.

Table 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 Networks Initiative	Energy Efficiency Campaign	Information Campaign on Climate Protection (cp. EPBD)
Regulatory	Smart Metering Energy audit obligation for non-SMEs	Top Runner Strategy	EU-related: Energy Performance of Buildings, EPBD (Directive, 2002/91/EC & Directive, 2010/31/EU)
		EU-related: Ecodesign Directive for Energy-using Products (Directive, 2005/32/EC) & Ecodesign Directive for Energy-related Products (Directive, 2009/125/EC)	
	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).

- 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. DR is also a method to support the integration of renewable energy sources. However, DR does not necessarily result in energy savings, but should not be punished with higher taxes. A bonus for flexibility in case of energy storage is already partially integrated in regulations, but could be extended in favour of DR measures e.g. by untaxing loads used for DR from electricity taxes.
  - 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 (e.g. by covering a share of the daily fee for consultations and providing low-interest loans for energy efficiency investments). 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 thus are compatible with goals of DR (e.g. *Act on the Promotion of Renewable Energies in the Heat Sector* – it governs the preferential feeding-in of electricity from renewable sources into the grid and guarantees their producers fixed feed-in tariffs). Besides changing the energy carrier to renewable sources, the use of the flexibility potential 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 incentivize 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 (Boβmann 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.

4. Discussion of policy recommendations

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. 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. Another issue is the profitability of measures, which is low (especially on the spotmarket) and satisfactory business cases rarely exist. Profitability and suitability of measures are strong driving forces in decision making. The suitability of DR relates to size and subsector of companies and depends on 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:

4.1. Facilitation of market participation

- 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.
- Further regulatory support for the practical implementation and improvement of potentials of DR, e.g. by promoting the "smartness indicator" of buildings and labelling and standardizing (e.g. Ecodesign) to give clarity and facilitate to get informed.
- 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.

4.2. Incentivizing participation in DR

- 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.

4.3. Promotion and information for DR

- 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.

5. Conclusions and policy implications

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% of the companies have conducted DR compared to 48% in case of EE, cp. Table 2). 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. The analyses revealed 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, the attitude towards DR measures has a significant impact (i.e. whether DR are regarded as important in the future and contributes to the energy transition). 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. 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.

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 realised. 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.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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Appendix

Table 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 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.

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