LESSONS LEARNT FROM THE UPTAKE OF ENERGY AUDITS AND ENERGY MANAGEMENT SYSTEMS IN GERMANY

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Abstract

Promoting energy audits and energy management systems is a core part of the German and European policy mix for industry. The European Commission established mandatory energy audits for large enterprises in its Energy Eiciency Directive and concurrently encourages the widespread use of energy audits among small and medium sized enterprises (SME). In addition, the German government has promoted the uptake of energy audits and certified energy management systems by two energy tax relief schemes as well astwo funding schemes both for large enterprises and for SMEs. As a result, the majority of ISO 50001 certified companies across the world are from Germany. Based on a literature review of 36 papers, this article first analyses barriers to energy audits and energy management system. In a second step, on the basis of five different data sets the current state of diffusion of energy audits and management systems in Germany is presented followed by an empirical analysis of the impacts of energy audits and energy management systems. About one fourth of the Germany industrial companies have currently an energy management system in place. Our findings suggest that energy audits and energy management systems both lead to an increased uptake of energy efficiency measures in industry. Further research is needed on barriers with regard to organizational concepts such as energy audits and energy management systems as well as on the impact of these concepts on the energy efficiency progress in the long-run.

1 Introduction

Energy efficiency as a 'first fuel" (IEA 2014) and cost effective way to achieve a decarbonised society is also highly relevant for climate change as well as for the enhancement of the security of energy supply as it reduces greenhouse gas and other emissions as well as the overall energy consumption. However, due to several barriers (e.g. Schleich 2009, Schleich & Gruber 2008) and market failures a large un-tapped potential for cost effective energy efficiency measures, especially in the industrial sector, remains (e.g. Boßmann et al. 2012). Energy audits and energy management systems are important concepts and promising means for partially overcoming such barriers (Schleich et al., 2015). German (as well as European) policy-makers therefore strive to enhance the implementation of energy audits and energy management systems in companies. To achieve this goal, different policy instruments have been established. For an adequatel design of these instruments in the future an understanding about the current uptake of energy audits and energy management systems as well as insights on their impact are crucial. Therefore, it is the aim of this paper is to analyse the current state of diffusion of energy audits and energy management systems fostered by different policy instruments in Germany. Based on a literature review, we analyse the origin of different barriers to energy efficiency in general as well as regarding energy audits and energy management systems in partiuclar.We also empirically investigate the impacts of those instruments on the company's activities in the field of energy efficiency.

This paper is organized as follows: Section 2 provides further information on the German policy background regarding energy audits and energy management systems. Section 3 gives an overview about present research on barriers related to companies' activities in the field of energy efficiency. In the following Sections 4 and 5, describe the data set and the methodology used for the analysis. In section 6, the main results both for the current state of diffusion of energy audits and management systems in Germany as well as for the impacts of those instruments on the company's activities in the field of energy efficiency are presented. This is followed by a discussion of policy implications in section 7 and leads over to our conclusions in section 8.

2 Policy Background

Energy audits and energy management systems are both suitable concepts to increase the energy efficiency progress in institutions. While energy audits are primarily used to increase knowledge on energy consumption as well as on energy saving opportuntities and as a key enabler for the implementation of energy-efficient measures, energy management systems are understood as a continuous procedure to improve the energy efficiency progress. According to the Energy Efficiency Directive (EC 2012), an energy audit can be defined as "a systematic procedure with the purpose of obtaining adequate knowledge of the existing energy consumption profile […], identifying and quantifying cost-effective energy savings opportunities, and reporting the findings".
Energy management systems are a systematic way of analysing the procurement, conversion and use of energy within an organisation under environmental and economic objectives (VDI 2007). This concept has been standardised as Norm EN 16001 until 2011 and as ISO 50001 since then. Since the diffusion of these two concepts was comparatively slow in the last decade, German (and also international) policy makers decided to support the uptake by establishing different policy instruments.

In Germany, a broad policy mix exists to encourage and force the uptake of energy audits and energy management systems. With the exception of one regulatory instrument, the majority of instruments in Germany that aim to promote the implementation of energy audits and energy management systems in industrial companies are subsidies and incentives as well as information instruments. Table 1 gives an overview about the different instruments in the two areas 'energy audits' and 'energy management systems' as well as visualises their target groups.

	Large enterprises (non-SMEs)		SMEs	
	Energy management	**Energy audit**	**Energy management**	**Energy audit**
Special equalization scheme	X			X
Eco tax cap for manufacturing industry	X			X*
Mandatory energy audits (Art. 8 EED)	X**	X		
SME Energy Consulting Programme				X
Support Programme for Energy Management Systems	X***	X***	X***	X***
* Companies with electricity consumption <5 GWh can introduce alternative systems. ** Companies that are subject to mandatory energy audits may alternatively introduce an energy management system and conduct the energy audit in this context. *** Companies which have already applied for are the 'special equalization scheme' or the 'eco tax cap for manufacturing industry' are not eligible for funding.				

Table 1: Overview of policy instruments targeted at the implementation of energy audits and energy management systems in Germany

The basic requirements of the instruments are the following:

- *Special equalization scheme:* This scheme in the Renewable Energy Sources Act (EEG) provides for a reduction of the renewables surcharge (EEG surcharge, also called EEG reallocation charge) for energy-intensive companies. Beneficiaries pay the full EEG surcharge for the first gigawatt hour and then 15% of the EEG surcharge for every kilowatt hour of electricity they consume above this. This burden is limited to a maximum of 4% of the respective enterprise's gross value added or, in the case of enterprises with an electricity-cost intensity of 20% or more, a maximum of 0.5% (cap/super-cap in the EU's Guidelines on State aid for environmental protection and energy). As a prerequisite to obtaining the reduction of the renewables surcharge, applicants have to operate a certified energy or environmental management system (in line with DIN EN ISO 50001, formerly 16001 or EMAS); companies with an electricity consumption of less than 5 GWh can operate alternative systems (e.g. according to DIN EN 16247-1) that improve energy efficiency (Federal Ministry for Justice and Consumer Protection 2015).
- *Eco tax cap for manufacturing industry*: This tax cap reduces electricity tax burdens on industrial companies. This so-called surplus settlement is available upon request to companies from the manufacturing sector and enables the redemption of up to 90% of electricity and/or energy taxes paid. To gain this reduction the energy intensity has to be continuously reduced by the manufacturing industry as a whole. The legal targets for this energy intensity are 1.3% annually for the period from 2013 to 2015 and 1.35% for 2016. Companies that are granted tax caps have to provide proof that an energy management system will have been introduced by the end of 2015. Small and medium-sized companies are allowed to implement an alternative system (e.g. an audit in line with DIN EN 16247-1) (Federal Ministry for Justice and Consumer Protection 2014).
- *Mandatory energy audits*: Article 8 of the Energy Efficiency Directive (EED) (EC 2012) requires all EU Member States to oblige large companies to conduct an energy audit.[1] To transpose Article 8 EED for large companies, the German Parliament adopted an amendment to the Act on Energy Services and Energy Efficiency Measures (EDL-G) and thereby obliged large companies (defined as non-SMEs) to regularly conduct an energy audit (Federal Ministry for Justice and Consumer Protection 2015).
- *SME Energy Consulting Programme*: This programme aims to help companies to overcome deficits in know-how and other ob-stacles concerning energy usage and offers financial

[1] Article 8 also encourages the widespread use of energy audits among SME without a formal. For this purpose, the EED requires the Member States to develop instruments that encourage SMEs to undergo energy audits and to implement their recommendations obligation (for an overview about the instruments taken see Nabitz et al. 2016a).

support for screening and detailed energy audits in SMEs by qualified and independent consultants. Companies with an-nual energy costs above EUR 10,000 can get funding of 80% of the eligible costs (up to EUR 8,000) and companies with annual energy costs of up to EUR 10,000 can ob-tain funding of 80% of the eligible costs (up to EUR 800) (Federal Ministry for Economic Affairs and Energy 2014). The evaluation of the Programme by Mai et al. (2014) evaluation of the programme attributes a positive effect on the implementation of energy efficiency measures in the wake of the audits.

- *Support Programme for Energy Management Systems:* This programme supports the certification of energy management systems for companies and provides funding in four categories: (1) Funding for the initial certification of an energy management system, (2) Funding for the purchase of metering technology and/or software for an energy management system, (3) Funding for external energy consultation and (4) Funding for training costs of employees. Generally, the total sum per company is limited to EUR 20,000 in 36 months (Federal Ministry for Economic Affairs and Energy 2015).

In comparison to other EU Member States Germany has a long tradition in terms of the promotion of energy audits and energy management systems which meanwhile results in a variety of policy instruments (see Table 1). As the empirical analysis will show, these instruments contribute to a great extend to a diffusion of the two concepts 'energy audits' and 'energy management systems'. The analyses by Schleicht et al. (2015) on the impact of the funding program for energy audits in SMEs and by Nabitz et al. (2016b) on the funding program for energy management systems already investigate the impact of such policy instruments on a more detailed level. However, furhter research on the impact of these instruments on a policy mix level also considering instrument interactions is needed.

3 Barriers related to companies' activities in the field of energy efficiency

Although many investments in energy efficiency potentially generate a high internal rate of return and are thus cost efficient, German industrial companies and other institutions are still reluctant to implement such energy-efficient measures due to a number of barriers. Of course a lot of German companies already leveraged existing energy efficiency potential in the past. However, there are still numerous opportunities to increase energy savings. In this context, barriers have to be differentiated in terms of both the implementation of energy audits and/or energy management systems as well as regarding the adoption of energy-efficient measures.

There are numerous conceptual and empirical studies on barriers to energy efficiency (to name a few: Gruber & Brand 1991; Jaffe & Stavins 1994; Schleich 2009; Cagno et al., 2013; Trianni et al., 2016, see also TableAnnex 1). In these studies, a barrier is basically understood as a mechanism that prevents energy-efficient measures (investments in technical measures or behavioral changes) from being implemented. Sorrell et al. (2004) define it as a '[…] a postulated mechanism that inhibits a decision or behavior that appears to be both energy efficient and economically efficient.' The analysis of barriers in this section is methodologically based on a systematic literature research. For this purpose, research on both the relevant work on barriers to the introduction of energy management systems and audits, as well as on the implementation of energy efficiency measures was carried out. On the portals Science Direct and Scopus as well as in Conference Proceedings with the main search items 'barrier', 'energy efficiency' and 'energy management' a total of 36articles were identified as relevant, which were published with a few exceptions in the years between 2010 and 2016 (see TableAnnex 1).

Empirical investigations on barriers mainly focus on the adoption of energy-efficient measures in general under consideration of different classification mechanisms (e.g. Schleich 2009; Cagno et al., 2013; Trianni et al., 2016). In the present literature there is seldom made a reference to obstacles regarding the introduction of an energy management system or an energy audit. However, some authors suggest concepts that divide the process of implementing energy-efficient measures into

different phases[2] where the importance of different barriers varies considerably (Trianni et al., 2016, Cagno et al., 2013, Hasanbeigi et al., 2010). Energy audits and energy management systems can be located in the early stages and have been identified as key enabler and helpful concepts to adopt energy-efficient measures in companies (e.g. Fleiter et al., 2012; Schleich et al., 2015). Consequently, conclusions to barriers regarding the implementation of energy audits and energy management systems can be drawn to different barriers in these stages.

In the early stages behavioural barriers and a lack of awareness play an important role as in these stages creating awareness of energy efficiency and gaining knowledge on the energy consumption profile as well as on energy saving possibilities are the most important aspects (Trianni et al., 2016). This suggests that behavioural barriers are relevant to the introduction of energy audits and energy management systems whereas economic barriers are only intensified in a relatively 'close-to-implementing phase'.

In the recent decades, the importance of obstacles to the implementation of energy-efficient measures has already been extensively discussed in the literature (e.g. review papers from Brunke et al., 2014 or Trianni et al., 2016). We therefore limit ourselves in this section to key aspects especially relevant for the two organisational concepts. With respect to the concrete implementation of energy-efficient measures, the most frequently mentioned barriers in the reviewed literature are financial barriers, in particular access to capital, access to information and their evaluation as well as behavioural barriers such as simple decision-making routines as well as lack of awareness and/or lack of prioritization by a company's management (Cagno et al., 2014).

In detail, there are differences regarding barriers according to industry, energy intensity, company's size and production process. Among others, SMEs perceive higher barriers than larger companies. This may be due to the fact that access to capital is problematic for small businesses. Hasanbeigi et al. (2010) point out that uncertainties are a major obstacle to SMEs as they have less capital and therefore only cautiously invest. Decision patterns (as a behavioural barrier) seem to play a greater role for smaller companies (Cagno et al., 2014). A further problem could be lack of competences, e.g. because no specific personnel is responsible for energy tasks (Cagno et al., 2014). Large companies, on the other hand, may have more resources and technical skills to implement energy efficiency measures (Chai & Yeo 2012).

In summary, the consideration of the phases in the finding and implementation process of energy-efficient measures allows a more targeted design of political interventions. Regarding the introduction of energy audits and energy management systems, behavioural barriers which usually arise within the company, play an important role. On the other hand, economic barriers are particularly relevant when it comes to the concrete planning and implementation of a measure. Another important aspect is the recognition that the barriers are not independent of each other (Cooremans 2012; Chai & Yeo 2012). Furthermore, the obstacles to the implementation of specific measures seem to be depended on the specific measures and thus differ from the general barriers to energy efficiency (Cagno et al., 2014).

4 Data

To analyse the status of diffusion of the two instruments, energy audits and energy management, as well as to investigate their impact we use five different data sets. These data sets were partly collected in the context of evaluations of funding programs as well as partly independently collected in the years 2014, 2015 and 2016 (see Table2).

[2] Trianni et al. (2016) e.g. split the steps of the decision-making process into (1) generation of awareness, (2) identification of needs and opportunities, (3) technology identification, (4) planning of the intervention, (5) financial and economic analysis, and (6) implementation, start-up and training.

Table 2: Overview of data sets

Data set	EMS2015	EBM2014	GHD2016	Effizienzfonds 2016	RE2016
Name of data set	European Manufacturing Survey	Energy audits in SMEs ("Energie-beratung Mittel-stand")	Rational use of energy in the trade, commerce and services sector	Evaluation of the funding program "energy management systems"	Rational use of energy in industry
Year of survey	2015	2014	2016	2016	2016
Sectors	Manufacturing industries	Industry & trade, commerce and services	Trade, commerce and services; manufacturing industries < 20 employees	Industry & trade, commerce and services	NACE 22, 25-30
Sample size	1,282	1,471	336	246	402
Particu-larities of the sample	Representative data sample of the manufacturing industries (>19 employees)	All companies in the sample had an energy audit	-	Majority of companies in the sample has an energy management system	Subsample of the EMS2015 Data set
Further Infor-ation	Mattes et al., (2015)	Mai et al. (2014), Schleich et al., (2015)	-	Nabitz et al., (2016b)	Mattes et al., (2016)

The first data set is based on the European Manufacturing Survey. This survey is carried out by Fraunhofer ISI every three years and consists of a representative sample of the manufacturing sector in terms of the distribution of company size and industry affiliation (Mattes et al., 2015). In terms of content, the use of technical and organizational innovations in production and the resulting improvements in the ability to perform in the manufacturing sector have been surveyed. Due to the time series data this sample is especially relevant for the status of diffusion of energy managements systems. Fraunhofer ISI together with IREES collected the second data set, 'Energy audits in SMEs", in the context of the evaluation of the funding program 'Energy Consulting for SME' (Mai et al., 2014). As a result, a subsidized energy audit was carried out in all surveyed companies. Within the framework of the project 'Evaluation of the Energy Efficiency Fund', the funding program 'Promotion of energy management systems' was evaluated and a survey was carried out among the subsidized companies. In this third data set, the majority of companies has already installed an energy management system (Nabitz et al., 2016b). Thus, this sample is particularly suitable to assess the impact of energy management systems. The fourth data set 'Rational use of energy in industry" is a subsample of the European Manufacturing Survey and contains information on the rational use of energy, energy monitoring and the relevance of energy efficiency in industry (Mattes et al., 2016). In addition, the fourth data set 'Rational use of energy in the trade, commerce and services sector" covers analogous data on the rationale use of energy for these branches.

Table 3: Descriptive overview about control variables in the different data sets

	EBM2014	GHD2016	Effizienz-fonds2016	RE2016
Number of employees: median	35	35	193	59
Number of employees: average (standard deviation)	54 (56)	377 (2176)	465 (906)	265 (1148)
Share of companies with 1 - 20 employees	36%	36%	5%	2%
Share of companies with 21 - 50 employees	29%	26%	13%	43%
Share of companies with 51 - 250 employees	35%	25%	43%	40%
Share of companies with more than 250 employees	0%	14%	39%	15%
Share of organizations with energy manager	41%	variable not collected	variable not collected	variable not collected
Share of organizations which use energy indicators	variable not collected	67%	89%	48%
Share of organizations which have an energy target	variable not collected	43%	83%	38%

5 Methodology

To analyse the structure and distribution of the existing data sets, univariate descriptive analyses, by means and standard deviations, are carried out first. Since the data sets always represent one particular sampling of the entire population, the mean value in the data set can differ from the mean of the respective sample. For this reason, the mean of each sample is provided with an uncertainty band, the so-called confidence interval. In a second step, to analyse whether a statistically relevant difference exists between companies with an energy management system (‘treatment group’) and companies without an energy management system (‘control group’) we perform simple t-tests using the t-test function in R (R core team 2016) which allows for unequal variances. In a third step, we perform a regression model and calculate marginal effects. For the evaluation of influencing factors, which are relevant with regard to the effect of energy audits and energy management systems, more than one influencing factor is interesting. Thus, multivariate statistical methods are used. This allows us to determine the effects of several variables, measured as independent variables (e.g. energy cost and size) on a dependent variable (e.g. the implementation of an energy management system).

6 Results

6.1 Diffusion of energy audits and energy management systems

To inestigate the status of diffusion of energy audits and energy management system we analyse share of companies that have implemented energy audits as well as energy management systems divided into subgroups according to the size of the company (employee criterion).

6.1.1 Diffusion of energy audits

To analyse the share of companies that have implemented energy audits we use the 'RE2016' data set since it provides a representative sample of German companies (Mattes et al., 2016). The overall share of companies with an audit is 58 ± 5 % (95% confidence interval). As shown in Figure 1, our findings suggest an increase of the share of companies with an energy audit with growing company size. The total average of 58 % is highlighted as a vertical gray line in the figure.

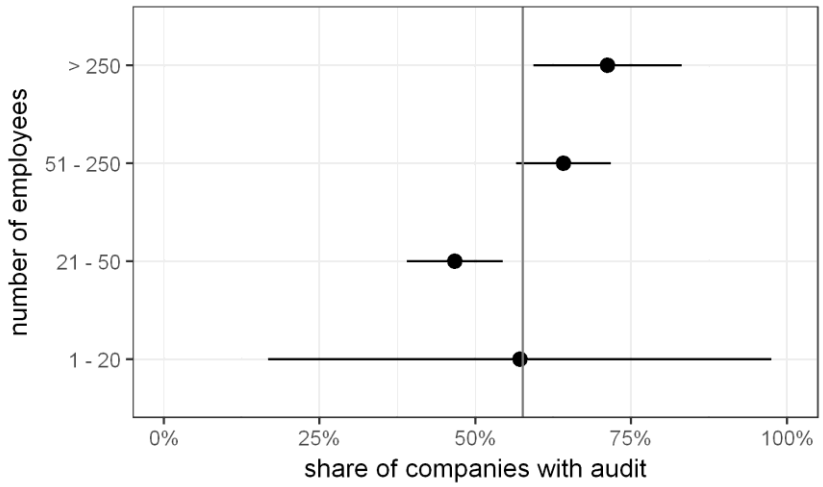

Figure 1: Share of companies with audits by company size. (Horizontal bars indicate 95 % confidence intervals. The gray vertical is the total average.)

We compared the share of companies with completed energy audits among the different data sets. The 'Effizienzfonds 2016' dat set has a similar sample, and the resulting share of companies with an energy audit in the different company size groups are similar to the findings in the figure above with an overall share of 64 ± 7 % (95% confidence interval). Although this data set is not representative, the results are consistent with the previous findings. Furthermore, the trade and services sector generally has a lower share of implemented energy audits than the industrial sector.

6.1.2 Diffusion of energy management systems

We can use the large 'EMS 2015' representative data set to gain understanding about the present state and time evolution of energy management systems in the German manufacturing industry. To back cast the share of companies in Germany with an energy management system, we use the year of introduction of the energy management system as stated by the companies in the survey. Figure 2 shows the result differentiated by company size. The share of companies with an energy management system in Germany has increased steadily over the past decade, and the share is very likely to change further in the future. Furthermore, the diffusion of energy management systems in Figure 2 follows the typical S-shaped diffusion curve well-known from the diffusion of innovations (Rogers 1995).

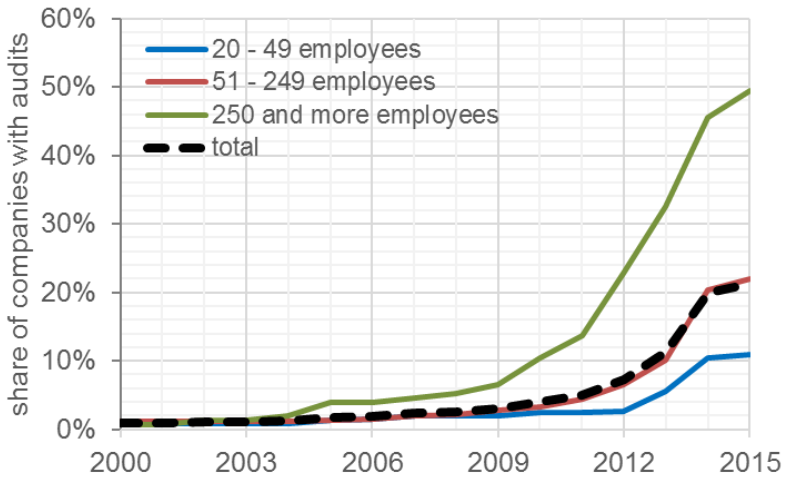

Figure 2: Diffusion of EMS over time in the German manufacturing industry

The present state of diffusion of energy management systems in the German industry can be further analysed with the different surveys introduced in the data section. Figure 3 presents the share of companies in the German industrial sector that have an energy management system in place according to three surveys and differentiated by company size. The overall average share is 27 ± 2.5 % (95% confidence interval). The different samples show slightly averages of 31 ± 3 % for the EBM2014 (N = 722), 20± 4 % for the RE2016 (N = 395) as well as of 18 ± 9 % for the GHD2016 (N = 73). Please note, that the different surveys presented in the graph represent different samples. Thus, no evolution over time can be derived from these graphs. Again, Figure 3 shows that the share of companies with EMS notably grows with company size as measured by number of employees. Please note missing confidence band for the largest company size group of the EBM2014 survey in Figure 3, which stems from the fact that the EBM2014 survey contains only four companies with more than 250 employees and none of it had an EMS. Overall, about one fourth of the German industry currently has an EMS and the share can be expected to grow further in time.

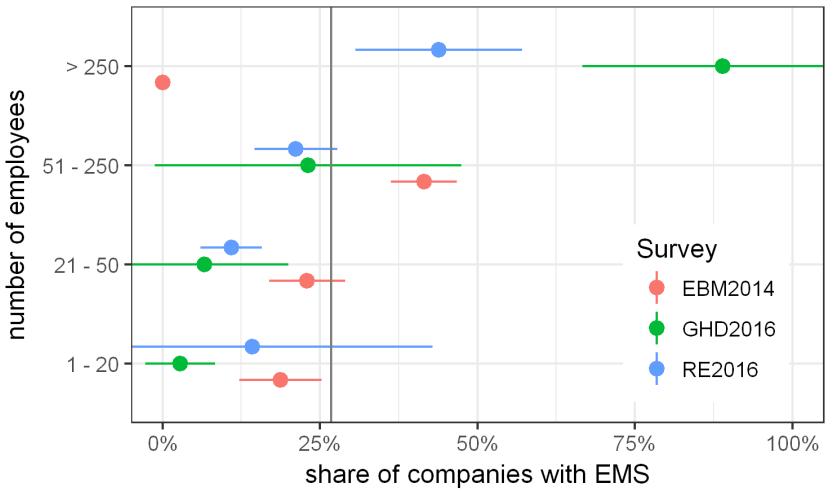

Figure 3: Current state of Diffusion of EMS in the German industry according to different data sources (colors) and company size

6.2 Impact of energy audits and energy management systems

The impact of energy management measures can be measured in different ways. To investigate this impact of an energy management system, we use two primary variables for the measurement. First, we analyse the proportion of implemented energy efficiency measures in organizations with an energy management system compared to organizations without an energy management system (see section

6.2.1). In a second step, we analyse the share of organizations with energy management system that have implemented energy efficiency measures in a technology area compared to the proportion of organizations without an energy management system that have implemented energy efficiency measures in a technology area (see section 6.2.2). The direct comparisons are always based on a control group. Thereby, a meaningful assessment of the impact is possible.

6.2.1 Share of implemented energy efficiency measures per company

The 'Effiziendyfonds2016' data set contains the number of suggested, as well as implemented, energy efficiency measures per company. Based on these two variables we calculate the adoptiton rate (defined as share of implemented to identified energy efficiency measures). Thus, we use this data set to analyse the impact of audits and energy management systems on the share of implemented energy efficiency measures per company. Figure 4 shows the average shares of implemented energy efficiency measures in companies with and without energy audits as well as with and without an energy management system (with 95% confidence bands). We observe a slight increase in the average share of implemented measures for audits and a clear increase for energy management systems.

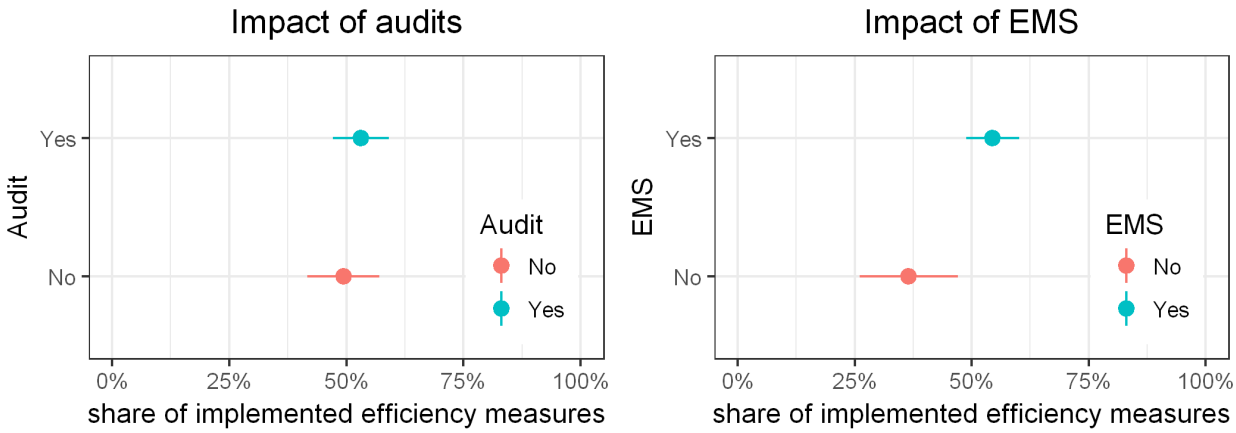

Figure 4: Average share of implemented energy efficiency measures in companies with and without audit as well as with and without EMS in the German industry (Horizontal bars indicate 95 % confidence intervals)

We use average marginal effects of a logit regression to quantify the impact of the energy management measures. We ran a logit regression of the presence of an audit and energy management system on the implementation of at least half the suggested energy efficiency measures ('Effizienzfonds2016' data, N = 180). Further control variables are the use of energy saving targets and energy usage indicators within a company. Table 2 shows the average marginal effects of logit regression indicating that an audit increases the likelihood to implemented more than half the suggested energy efficiency measures by 17 percent points (marginally significant) and an EMS by 26 precentage points (highly significant). Furthermore, the included control variables have a significant impact on the likelihood of a company implementing energy efficiency measures.

Table 2: Average marginal effects of audits and EMS on the share of adopted energy efficiency measures in the German industry

Variable	Marginal effect	Std. error	z-value
Audit	+17.2%†	9.2%	1.88
Energy Management system	+25.6%**	9.7%	2.65
Energy saving target	−41.3%**	12.9%	-3.20
Energy usage indicators	+42.9%***	4.6%	9.34

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '†' 0.1.

The average marginal effects demonstrate the positive impact of the energy management measures on the implementation of energy efficiency measures. The regression results differ from the simple linear

effects shown in Figure 4 since they include the joint effect of several variables, i.e. both audit and EMS as the same time as well as the control variables (multiple regression). Furthermore, our findings are consistent with the more detailed analysis of Schleich et al. (2015). Overall, both an audit and an energy management system increase the average share of implemented energy efficiency measures per company.

6.2.2 Share of companies adopting energy efficiency measures per technology

The second way to quantify the impact of energy management measures uses the different shares of companies that have implemented energy efficiency measures. Please note that the implementation per company is a binary variable now: A company either has or has not implemented measures in the realm of a given energy consuming technology sector. We use the 'RE2016' data set to analyse the implementation shares for different technology sectors. Figure 4 shows the share of companies that have implemented energy efficiency measures differentiated by companies with or without audits and with or without EMS.

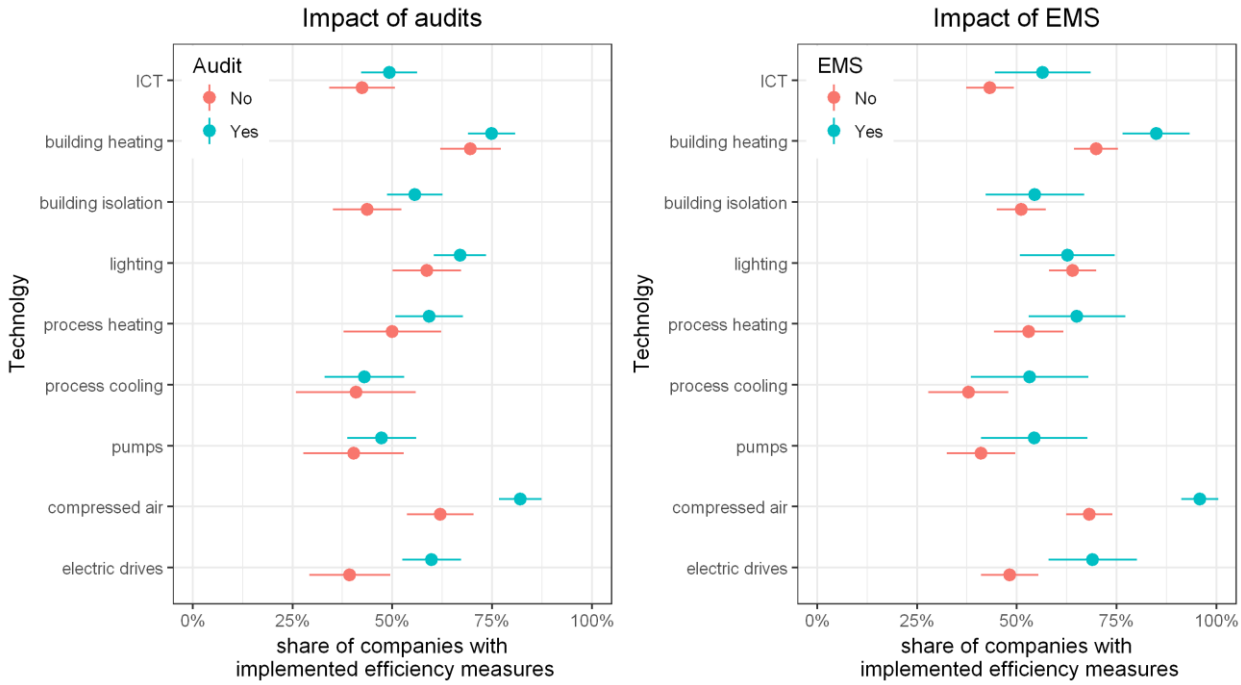

Figure 4: Average share of companies that have implemented energy efficiency measures in technology sectors with and without audit (left panel) as well as with and without EMS (right panel) in the German industry (Horizontal bars indicate 95 % confidence intervals)

To analyse the effect of an energy management system in more detail, the activities with regard to different cross-cutting technologies in the area of production and infrastructure of the companies with and without an energy management system are compared with each other. For this purpose, we compare the 'treatment' group based on the 'Effizienzfonds2016' data set with a control group based on the 'RE2016' data set. The analyses presented in this section are derived from a study evaluating the funding program on energy management systems (Nabitz et al., 2016b).

Using the t.test function in R (R core team 2016) which allows for unequal variances, we perform simple t-tests. As shown in Table 4, we observe a statistically significant difference between the two groups, especially in the areas of technology of electrical drives, compressed air systems and lighting (see
Table 4). In these areas the adoption rate (defined as the share of companies which implemented measures in the respective technological area) in the 'treatment' group is significantly higher than in the control group. Concerning heating systems in buildings, we do find a weakly significant difference between the two groups, but in the opposite direction.

Table 4: T-Tests of the two groups 'with and without energy management system' by share of companies which implemented energy efficiency measures in the different technological areas

Technological area	Group	N	Share of companies (percentage of N) with mplemented measures	Difference	t-value	p-value	Significance level
Electric drives	EMS	72	73.6 %	29.8 %	3.904	0.000	***
	Without EMS	80	43.8 %				
Compressed air	EMS	86	79.1 %	17.7 %	2.778	0.006	***
	Without EMS	114	61.4 %				
Pumps	EMS	64	40.6 %	-2.8 %	-0.280	0.765	
	Without EMS	53	43.4 %				
Process cooling	EMS	54	46.3 %	6.8 %	0.646	0.520	
	Without EMS	38	39.5 %				
Process heat supply	EMS	55	45.5 %	2.8 %	-0.306	0.760	
	Without EMS	60	48.3 %				
Heating systems in buildings	EMS	75	42.7 %	-14.4 %	-1.950	0.052	*
	Without EMS	112	57.1 %				
Building envelope	EMS	77	39.0 %	-3.1 %	-0.432	0.666	
	Without EMS	114	42.1 %				
Lighting	EMS	87	89.7 %	22.5 %	4.202	0.000	***
	Without EMS	125	67.2 %				
Information and communication technologies (ICT)	EMS	80	45.0 %	2.3 %	0.315	0.753	
	Without EMS	124	42.7 %				

* Significance level $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$; Source: Nabitz et al. (2016), based on subsamples of the data sets 'Effizienzfonds2016' and 'RE2016'

'Low-hanging fruits' which are measures that are comparatively easy-to-implement and therefore are usually adopted by companies in the first instance, are implemented much more frequently by companies operating an energy management system. On the other hand, more capital-intensive measures, such as those in the field of building heating systems seem to be less likely to be implemented by companies with an energy management system. This may be the case due to the fact that these are subject to long-term investment cycles. The slight differences in the single-digit percentage range in the areas of pumps, process heat supply, building envelope, as well as ICT, do not suggest any difference between the two samples on the basis of the empirical data. Thus, based on our data set no conclusions can be made for this area. With regard to the interpretation of the results, it must also be taken into account that although the distribution of the size of the companies is similar in both samples, there is no complete match with regard to the affiliation of sectors of the companies. In addition, the shares of those companies that have implemented measures in the individual technology areas do not allow any conclusions onto what extent they were active. This is due to the fact that the data was surveyed binary (question if measures implemented or not implemented (1/0)). For example, in the area of compressed air it is not clear whether leakages have been eliminated or wether the compressed air compressor has been replaced during the course of the energy efficiency measure. However, irrespective of these limitations, our findings suggest that companies with an energy

management system implement significantly more energy efficiency measures than companies without an energy management system.

7 Discussion and Policy Implications

Regarding a further diffusion of energy audits and energy management system it is particularly important that the perception of barriers by the institutions adopting these concepts is reduced. Our literature review on barriers has shown that particularly the consideration of the phases in the finding and implementation process of energy-efficient measures allows a more targeted design of political interventions. Regarding the introduction of energy audits and energy management systems, behavioural barriers which usually arise within the company, play an important role. Thus, political interventions aiming at a promotion of these concepts should take into account the dependence of the different barriers (especially in early stages of the decision process) as a policy instrument that addresses only one barrier may have little effect.

Of course, to adequately design these instruments knowledge about the state of diffusion is crucial in order to assess the needs of the institutions. As our analysis shows about one fourth of the German industrial companies already have an energy management system in place. Even every second large enterprise has an energy management system. However, it seems that the uptake in small and medium-sized enterprises needs further support.

Regarding the data for the statistical analysis, there data availability is challenging. At the Federal Statistical Office in Germany, there is currently no representative data set on the state of the distribution of energy audits and energy management systems in industry as well as in other institutions available. Thus, to achieve an approximation research tries (also due to economic reasons) to close this gap with the collection of subsamples. The representative data set 'EMS 2015' presented in this article provides a first indication of the state of diffusion of energy management systems. With regard to the other data sets, it must be acknowledged that these were partly generated within evaluation projects and therefore can only provide an approximation with respect to the degree of dissemination as they are not fully representative. However, to analyse the impact of energy audits and energy management systems no representative data set is needed. Thus, the 'Efficiency Fund 2016' dataset provides detailed information on the impact of energy management systems.

8 Conclusion

About one fourth of the Germany industrial companies have currently an energy management system in place. With our analysis we can show, that energy audits and energy management systems lead to an increased uptake of energy efficiency measures in industry. In addition, our findings show that as a result to the numerous policy instruments, the majority of ISO 50001 certificates worldwide have been issued in Germany. Across all company sizes every fourth company already has an energy management system in place. When considering only the large enterprises, every second company has a system in place. Only the uptake in small and medium-sized companies is not yet as advance as in large enterprises. Thus, policy makers may further support the introduction of such systems in those companies. Funding programmes are already available in Germany, but so far these have not been sufficiently exploited. One idea is tomake these more popular and as well to reduce bureaucratic burdens when requesting funding. With regard to the impact of the two concept our findings suggest that both an audit and an energy management system increase the average share of implemented energy efficiency measures per company compared to a company without such as system. In this context, ‘low-hanging fruits’ which are measures that are comparatively easy-to-implement are usually adopted by companies in the first instance whereas more capital-intensive measures are adopted at a later stage.

While findings on barriers to energy efficiency are transferable to the introduction of energy audits and energy management systems, there is still a need for research to study barriers in detail with regard to organizational concepts such as energy audits and energy management systems. Furhtermore, additional research which investigates the impact of energy audits and especially of energy management systems in the long-run is needed.

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Appendix

TableAnnex 1: Review of papers focusing on barriers in the context of energy efficiency

Author (Year)	Country focus	Sector	Company size	Methodology	Data set	N	Main results
Apeaning & Thollander (2013)	Ghana	Manu-acturing industry	n.a.	Empirical (qualitiative)	Semi-strucutred interviews	n=34	Main barriers: All barriers found relate to rational behaviour barriers and are linked to lack of policy framework. The two highest ranked barriers are lack of budget funding and access to capital. Third highest barrier: Other priorities for capital investment (i.e. lack of management awareness which can theoretically be linked to hidden cost, respondents mentioned energy cost were perceived as relatively unimportant by top management). Foruth highgest barrier (similar often mentioned): Technology is inappropriate at this site and technical risks such as risk of production disruptions.
Backlund et al. (2012)	-	Manu-acturing industry & trade, commerce and services	n.a.	Theoretical-conceptual	Literature review	-	Underlining the importance of energy management practices for energy efficiency potential. Energy efficiency potential is greater when including EMS compared to technology based definition. The higher potential (including energy management practices) is conceptualized as extended energy efficiency potential.
Bell et al. (2014)	New Zea-and	Wood drying	SME	Empirical (qualitiative)	Semi-strucutred interviews	n=20	The work examines the socio-technical regime of wood drying in New Zealand from the perspective of different cultures. The analysis concludes that socio-technical barriers are the main obstacle to the spread of heat pumps as energy efficiency technology in wood drying.
Blass et al. (2014)	USA (Cali-fornia, Ohio)	Manufacturing industry	SME	Empirical (econometric model)	Industrial Acess-Ment Database (IAC)	n=752 com-panies	Involvement of top management with an operational role (i.e. e.g. operational manager) has a positive influence on implementation of efficiency measures suggested in audit. Effect is stronger for recommendations that require process or equipment change. Top operation managers realize more of the identified energy savings than other employees, implement a higher percentage of recommended investments and adopt recommendations with longer payback.
Brunke et al. (2014)	Sweden	Iron & Steel industry		Empirical, mixed-methods (quantitative, qualitative)	Survey and follow-up interviews	n=23	Main barriers: internal economic and behavioural barriers. Energy management is of high importance (most important driver originating from within the company). Most important perceived barriers: technical risks (potential reasons: continous production process, more important for producers than downstream actors). Second and third most important barrier are limited access to capital and other priorities for financial ivnestment. One reason behind is the focus of companies on the core business since the effects of the financial crisis were still felt.

Author (Year)	Country focus	Sector	Company size	Methodology	Data set	N	Main results
Cagno & Trianni (2013)	Italy	Manufacturing industry (focus on metal, textile & chemi-cals)	SME	Empirical, case studies	Semi-strucutred interviews	n=71	Most important drivers (investments, but also culture, behaviour) are public financing, external pressures (e.g. rising energy prices or emission taxes) and long term benefits. Also internal drivers have non-negligibel relevance: management sensitivity, presence of ambition and entrepreneurial mind and information on technologies and information on practices (-> they recommend regional or local learning networks to spread knowledge and disseminate simple rules and good practices). Same order of importance rank access to experts and lower cost of consultancies (external competence is needed).
Cagno et al. (2014)	Italy	Metal	SME	Empirical, case studies	Industrial Assessment Center database	n=15	High importance of behavioral barriers. Differences between general barriers to energy efficiency and the barriers to concrete individual measures. Small companies are facing more barriers, especially in terms of competencies and behavioral barriers (difficulties implementing measures, suboptimal evaluation criteria).
Cagno et al. (2015)	Nether-lands	Manufacturing industry	SME	Empirical (qualitative)	Semi-strucutred interviews& survey	n=15	Voluntary agreements are a popular tool for energy efficiency in the Netherlands. They intend to address several barriers, but do not seem to have a positive effect on the improvement of the energy efficiency of SMEs. They do not appear to have a substantial influence on the economic barriers that are regarded as the most important obstacle in this context.
Chai & Yeo (2012)	-	diverse	-	Empirical (qualitative), case study	Semi-strucutred interviews& survey	n=16	Article discusses the interrelations between the barriers and supports the observation that small organizations face more technical and financial barriers than large companies. A high share of energy costs and a strong awareness of the company's social responsibility have a positive effect on energy efficiency. Large companies have more resources and technical capabilities to implement energy efficiency measures. Fear of production interruptions is a major obstacle to energy efficiency measures. Energy efficiency is difficult to observe at the level of individual components. This makes it more difficult to convince the top management of measures.
Cooremans (2012)	Swisse (Canton Geneva)	Electricity-intensive firms	SME und non-SME	Empirical (qualitative)	Semi-strucutred interviews& survey	n=35	In terms of general investments, the following conclusions are drawn: (1) Profitability plays an important but not a decisive role in investment decision-making. (2) The diagnostic phase is crucial. (3) Investment projects are in competition (other more promising, more profitable or 'more important' (core business, strategic interest)), investments are a central barrier to energy efficiency. The barriers are interdependent / influential: The article distinguishes four levels: basic barrier (information), symptom barrier (hidden cost, access to capital, risk etc), real barrier (no strategic character), hidden barrier (cultural dimension)

Author (Year)	Country focus	Sector	Company size	Methodology	Data set	N	Main results
Fleiter et al. (2012a)	-	-	-	Empirical (qualitative)	Literature review, survey with experts	n.a.	Focus is laid on the characteristics of EEMs. Point to the fact that generalization of studies on barriers is often not feasible because several factors need to be considered. Within there classification they relate different characteristics of EEMs to the adoption rate. They differeniate three areas: Higher relative advantage made up by internal rate of return, payback period, initial expenditure and non-energy benefits were high return, short payback periods, low initial expenditures and large non-energy benefits increase adoption. Ttechnical context: higher distance to core process increasing adoption. Organizational measures making adoption more likely than technology substituion as well as local effects and shorter lifetimes over system wide effects and long lifetimes. Information context: low transaction cost increasing adoption, lower knowledge requirements and cross-cutting sectoral applicability rather than process related.
Fleiter et al. (2012b)	Ger-many	Manufacturing and non-manufacturing industries	SME	Empirical (Explorative factor analysis, econometric model)	Survey	n=542	High investment costs and lack of capital as major barriers to the implementation of energy efficiency measures. No effect of the size of the company, technical risk is statistically significant. Quality of the audits and/or satisfaction with the audit influence the implementation positively.
Gruber & Brand (1991)	Ger-many	various	SME	Empirical (Quantitative)	In-depth interviews& survey	n=30	The survey results show that the share of the measures implemented increases with the size of the company and the amount of energy costs. Main barriers identified: lack of capital or prioritization to other investments, risk (with regard to the uncertainty of the future development of energy costs, companies want to wait, which new technical solutions arise), missing information, lack of suitable staff; futher sector specific results
Hasanbeigi et al. (2010)	Thail-lan	Textile, cement	-	Empirical	Literature review, survey, interviewswith experts	n=6 (cement) n=28 (textile)	Most important barrier is lacking management attention/ i.e. priority focused on production. Textile industry: mangament priority focused on production as top barrier, second and third ranked barriers relate to uncertainy about cost and performance of energy efficient technologies. Suggested rationale: SMEs often have little capital and hence need to be careful to invest/ fear future development might make technology cheaper or regulation tougher such that technologies do not comply.
Henriques, Catarino (2016)	Portugal	various	SME	Empirical	Survey	n>100	Barriers vary by sector: manfucaturing -> preceived cost and risk of production disrptuion, lack of time, cost of obtaining information, competing priorities for capital invesments and information or incentive gaps. Larger and more energy consuming enterprises -> limited access to capital, concerns about technical risk and lack of funding; Small enterprises -> lack of information, limited access to capital, low priorty on energy issues.

Author (Year)	Country focus	Sector	Company size	Methodology	Data set	N	Main results
Jackson (2010)	-	-	-	Analytical	Literature review, stylized examples	-	Review of capital budgeting practices indicates payback analysis as dominant tool for investment decision and low packback times as hurdle to screen out risky projects. This is consistent with satisficing or bounded rationality. Value at risk assessment is proposed to better judge investment projects considering potential returns and risk.
Kostka et al. (2013)	China	various	KMU	Empirical (regression model)	Semi-strucutred interviews& survey	n=480	Informational barriers are identified as a central barrier. In addition, there are the following factors: the importance of family businesses (high coordination costs and shared responsibility by several owners with different priorities), weak implementation of regulations, lack of political support from the government, lack of qualified staff, lack of awareness about energy-saving possibilities.
Kounetas et al. (2011)	Greece	Manufacturing industry	unspecified	Empirical (regression model)	Semi-strucutred interviews& survey	n=325 n=161	Information barrier is like a 'wall that does not allow a firm to view a wider EET landscape', 'resource constraints': when other acitivities which are vital for a firm's survival and growth, such as innovation, compete with the activities concerning the adoption of EETs for the firm's same resources, then the availability of resources to be assigned to the adoption and introduction of EETs is condensed.
Langois-Bertrund et al. (2015)	-	-	-	Theoretical, case studies	Literature recview	-	Main result: insufficient attention has been given to political-institutional barriers, paper proposes a classification of these obstacles: political obstruction, conflicting guidelines in the governance structure, and lack of policy coordination.
Lee (2015)	Corea	Steel	-	Empirical (descriptive)	Survey	n=13	Findings suggest that technical risk is the most important barrier to energy efficiency. Also capital budgets, lack of energy manager's influence, cost of identification and analysis of business opportunities and cost and difficulty of obtaining information are among the top barriers to closing the energy efficiency gap. Conflict of interest, lack of capital, cost of production disruptions and inappropriate technology at the site are ranked very low.
Martin et al. (2010)	GB	Manufacturing industry	-	Empirical (qualitative and quantitative, regression model)	Interviews	n=190	Firms are more likely to adopt climate friendly management practices if climate change issues are managed by the environmental or energy manager, and if this manager is close to the CEO.
Meath et al. (2015)	Aus-tralia	-	SME	Empirical (qualtitative)	Case study	n=202	Most important barriers (among others): Lack of time/staff commitments in other areas, financial barriers (even if ROI in less than 24 months), Lack of staff engagement or negative attitude from staff towards changes.

Author (Year)	Country focus	Sector	Company size	Methodology	Data set	N	Main results
Palm und Thollunder (2010)	-	-	-	Theoretical	Literature review	-	There are technical, social and organizational reasons why optimal enrgy efficiency measurements are not implemented. Simply perceiving a barrier may itself serve as a barrier to implementing energy efficiency measures in industry.
Ravi (2015)	India	Electronics packaging industry	-	Empirical (Interpretive Structural Modeling (ISM))	Literature review and interviews& survey	n =264 (survey)	The central barriers are: lack of awareness of the environment and sustainability, the lack of commitment of top management as well as short time horizons for decisions.
Schleich (2009)	Ger-many	Commerce, Services and Trade	-	Empirical (regression model)	Survey	n=2848	The statistically most significant barriers are found for the sub-sector of public administrations. The lack of information about energy consumption patterns and about energy efficiency measures, lack of staff time, priority setting within organizations, and – in particular – the investor/user dilemma are all relevant barriers.
Sorrell et al. (2011)	-	-	-	Theoretical	Literature review	-	Barriers to energy efficiency are multi-faceted, diverse and often specific to individual technologies; hidden costs (especially for SMEs), access to capital, lack of information. Different barriers usually occur at the same time, so that political intervention, which addresses only one obstacle, can sometimes be unsuccessful.
Timilsina et al. (2016)	Ukraine	Manu-facturing industry and trade	SME und non-SME	Empirical (Prinicpal Component Analysis)	Survey	n=509	Subgroup analysis for regions in Ukraine. Main barriers: High-level investment requirements, lack of government policies to support energy efficiency improvements, higher cost of capital, and lack of information and awareness.
Trianni et al. (2013a)	Italy	Manufacturing industry	SME	Empirical (Case Studies)	Semi-strucutred interviews& survey	n=48	The central perceived barriers in the examined sample are economic barriers (high investment, hidden costs and lack of profitability), as well as information barriers (e.g. information in energy contracts, unclear information from the technology manufacturers / suppliers and lack of information about costs and benefits).
Trianni et al. (2013b)	Italy	Metal industry	SME	Empirical	Survey	n = 20	Central barriers are perceived as the lack of resources used to improve energy efficiency, a lack of time and the presence of other priorities (for example, ensuring core business).
Trianni et al. (2013c)	Italy	Foundries	SME und non-SME	Empirical	Semi-strucutred interviews& survey	n=65	The study concludes that there is generally a lack of resources in the form of time and capital for energy efficiency measures. In the present research enterprises that had already performed an energy audit reported a higher perception of barriers.

Author (Year)	Country focus	Sector	Company size	Methodology	Data set	N	Main results
Trianni et al. (2016)	Italy	Manufacturing industry	SME	Empirical	Interviews	n=222	The results confirm the importance of economic barriers to SMEs. They also point out the importance of non-economic factors that are central to the implementation of energy efficiency measures in SMEs. In addition, companies that have already implemented energy efficiency measures generally face lower barriers, while audits only address individual barriers (behavior, information, organization).
Trianni und Cagno (2012)	Italy	Manufacturing industry (non-energy intensive)	SME	Empirical (ANOVA)	Semi-strucutred interviews& survey	n=128	The authors point out that bundling of SMEs of different sizes and sectors should be avoided as they differ in the perception of the barriers. Central barriers are access to capital, information on the possibilities of increasing energy efficiency and 'winning solutions'.
Venmans (2014)	Belgium	Ceramics, cement, lime	-	Empirical (regression model)	Semi-strucutred interviews	n=16	The main barriers are the availability of capital (depending on strict internal rules regarding budgets), as well as information and knowledge barriers.
Walsh & Thornley (2012)	GB	Process industry	-	Empirical (qualitative)	Data based on a workshop	-	The main barriers are lack of financial support, capital costs and problems associated with the site because of the use of low-temperature heat