Digitally driven energy management practices in SMEs – exploring potentials and barriers




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Abstract: Innovative digital technologies open up new opportunities for small and medium-sized enterprises (SMEs) to improve energy efficiency and energy management behavior. The question is: How far will SMEs be capable of profiting from the benefits of these new technologies? Using technology screening, this study identifies smart metering and mobile energy monitoring as digital technologies best addressing SMEs' specific demands. In addition, potentials and limitations of the technologies are investigated in two qualitative in-depth field trials. Barriers to adopting digitally enabled energy management practices are examined. The results indicate that visualising energy data enables SMEs to pursue new energy management practices for reducing energy consumption and costs (such as peak load analysis). SMEs need extensive guidance to identify and pursue these strategies. In conclusion, an exploratory adoption model for digitally enabled energy management practices is developed. Hypotheses for future experimental studies and policy implications are derived.

Keywords: digitalization, SMEs, digital technologies, smart energy, energy efficiency, energy management, smart metering, case study research

Digital ermöglichte Energiemanagement-Praktiken in KMU – Potenziale und Barrieren

Zusammenfassung: Innovative digitale Technologien bieten kleinen und mittleren Unternehmen (KMU) neue Möglichkeiten, ihre Energieeffizienz und ihr Energiemanagementverhalten zu verbessern. Allerdings ist unklar, inwieweit KMU in der Lage sind, von den Vorteilen dieser neuen Technologien zu profitieren. Anhand eines Technologie-Screenings identifiziert dieser Beitrag intelligente Messsysteme (IMS) und Energiemonitoring-Systeme (EMS) als digitale Technologien, die den spezifischen Anforderungen von KMU am besten gerecht werden. Darüber hinaus werden die Potenziale der Technologien anhand von zwei qualitativen Anwendungstests in KMU untersucht und Barrieren der Einführung digitaler Energiemanagement-Praktiken beleuchtet. Die Ergebnisse deuten darauf hin, dass Energiedatenvisualisierung KMU in die Lage versetzt, neue

Energiemanagement-Praktiken zur Senkung von Energieverbräuchen und Kosten anzuwenden (z.B. Spitzenlastanalyse). KMU benötigen allerdings eine umfassende Einführung, um diese Strategien zu identifizieren und zu verfolgen. Abschließend wird ein exploratives Modell für die Einführung digitaler Energiemanagement-Praktiken entwickelt. Es werden Hypothesen für zukünftige experimentelle Studien sowie politische Implikationen abgeleitet.

Stichwörter: Digitalisierung, KMU, Digitale Technologien, Smart Energy, Energieeffizienz, Energiemanagement, Intelligente Messsysteme, Fallbeispiel-Forschung

1 Introduction

Important pillars of corporate sustainability and sustainable behavior in companies are energy efficiency measures and energy management practises. Professional energy management can substantially reduce energy consumption and energy costs (Jalo et al. 2021, 3; Schulze et al. 2016). Yet, most small and medium-sized enterprises (SME) do not have professional energy management. In SMEs, energy management is rather informal (Sa et al. 2015), it is concentrated on one or few persons (Fawcett and Hampton 2020), and even energy intensive industries often lack long-term strategic planning (Posch et al. 2015; Thollander and Ottosson 2010). As a consequence, individual values and beliefs, daily practices, and routines often shape energy behaviors and consumption within SMEs (cf. Fawcett and Hampton 2020; König et al. 2020). In total, more than 22.5 million companies in the EU-27 are SMEs, representing 99.8 % of all companies (EU COM 2021). Thus, SMEs collective energy consumption is profound (IEA 2015). Moreover, SMEs have greater barriers to energy efficiency improvements than larger companies (Sorell et al. 2011, 48). For industrial SMEs, for example, Sorrell et al. (2011, 48) find that SMEs are more likely to lack relevant information about opportunities for improving energy efficiency and face higher costs for obtaining data on their energy costs and consumption. They are also less likely to have the necessary skills for implementing efficiency measures and for comparing their consumption with relevant benchmarks (Sorrell, Mallett, and Nye 2011, 48). Yet, there is hardly any research on barriers to and drivers for energy management practices in SMEs (cf. Jalo et al. 2021; but see König et al. 2020; Hampton 2019). Instead, research has focused on drivers for and barriers to investment decisions for energy efficiency measures (e.g. Cagno et al. 2013; Fleiter, Schleich, and Ravivanpong 2012; Trianni et al. 2017). Although providing profound research findings under the paradigm of the "energy efficiency gap" (Jaffe and Stavins 1994), this strand of literature does not take inefficiencies due to daily energy management practices and behavior into account (Backlund et al. 2012).

In order to improve energy management practices in SMEs, innovative digital technologies can now open up new opportunities (Warren 2017). Digital technologies can enhance energy management practices in SMEs, for example by collecting and analysing energy data. SMEs often do not have access to or make use of basic energy data (Janda, Bottrill, and Layberry 2014; Mickovic and Wouters 2020, 20; Rohdin and Thollander 2006). Data on energy consumption allows for developing and implementing specific energy management practices like peak and base load reduction, or benchmarking, in order to reduce energy costs, inform investment decisions, and decrease consumption. Initial experimental studies have addressed the question of how smart meters and visualization tools can nudge behavioral changes in order to reduce energy consumption and costs (e.g. Herrmann et al. 2018; Katzeff et al. 2013; Kimura et al. 2018; Komatsu and Kimura 2020). In the future, smart metering can provide automated advice, automation can replace inefficient user behavior, and SMEs can become active agents within smart energy grids by, e.g., providing demand-side flexibility.

However, there is hardly any empirical research on barriers to digitally driven energy management practices in SMEs. SMEs are especially diverse regarding how their electricity system is set up, what needs and related load profiles they have, and how knowledgeable they are. Accordingly, different digitally driven energy management practices can be relevant in different SME contexts. That is why it is necessary to first explore a wide range of barriers and outcomes, and to develop pertinent hypotheses and propositions for further inquiry. What digital technologies can best support and enhance SMEs energy management practices? How far will SMEs be capable of profiting from the benefits of these new technologies? And to what extent are SMEs capable of pursuing these management practices, what are the barriers?

This study explores potentials for and barriers to new digital technologies for improving energy management practices in SMEs. With hardly any research on barriers to digitally driven energy management practices in SMEs, this field study follows a qualitative and explorative approach. In a first step, technology screening was conducted to identify what digital technologies can best support SMEs' energy management practices. In a second step, on the basis of Yin (2014), two case study field trials were carried out to explore the potentials of and barriers to digitally driven energy management practices. In order to capture a broad range of potentials, issues and fundamental barriers, two SMEs were included with starkly contrasting electricity systems, power needs, and related load profiles. The first case is a recreational company with a complex and diverse electricity system. The second case study deals with the food retail sector, including energy analysis and benchmarking of three grocery stores, which are mostly structured similarly. In conclusion, preliminary policy implications as well as pertinent hypotheses and propositions for further inquiry are derived (cf. Yin 2014, 10), informing future experimental medium-n studies and study design.

2 Barriers to energy efficiency and energy management behavior in SME

The "energy efficiency gap" seminally describes differences in the de facto energy consumption and what would be consumed if the most cost efficient technologies were adopted (Jaffe and Stavins 1994). Overall, there is a consensus that policy intervention is necessary to reduce the energy efficiency gap. In a recent review of 40 years of energy efficiency research, Saunders et al. (2021, 143) conclude that "market barriers, market failures, behavioral failures, negative externalities, and issues of culture and norms justify policy intervention to improve energy efficiency." Market failures include, for example, misplaced incentives, imperfect information, bounded rationality, or lack of access to finance (Saunders et al. 2021, 143). A major strand of literature examines drivers for and barriers to cost-effective energy efficiency investments (Cagno et al. 2013) and the respective decision-making process (Cooremans 2012; Trianni et al. 2017). Cagno et al. (2013, 301), for example, propose a detailed and encompassing taxonomy for barriers to energy efficiency in firms, defining seven categories including 27 barriers, with categories including *technology related* barriers, *information related*, *economic*, *behavioral*, *organizational*, *competence related*, and *awareness*.

Albeit this profound research about the energy efficiency gap in firms in general, SMEs are still under-researched regarding their energy use, the potential for savings, and their energy-related decision-making (Fawcett and Hampton 2020, 1; see also Mickovic and Wouters 2020, 6). Fawcett & Hampton (2020, 2) conclude that two overarching findings, independent of sectors, are especially relevant for researching energy efficiency and management of SMEs (Fawcett & Hampton, 2020, 2): Firstly, *energy management is in the hands of one person*, most often the owner, or those of very few persons. Thus, individual beliefs and values of these persons are especially important for SMEs' energy management (Fawcett & Hampton 2020, 2). Secondly, *SMEs often have less time and technical skills* to consider energy efficiency opportunities compared to larger companies (Fawcett & Hampton 2020, 2). Additionally, Mickovic & Wouters (2020, 23) find on the basis of a literature review that *SMEs often lack information about their energy costs* and that they underestimate the savings potential of energy efficiency investments.

While barriers to and drivers for energy efficiency investment decisions of SMEs have been researched extensively, this is not the case with regard to energy management practices in SMEs (Jalo et al. 2021). Generally, the relevance of human behavior for energy use has been stressed early (Lutzenhiser 1993), but it is only recently that behavioral factors like day-to-day energy management practises are receiving growing attention both to define and to explain the energy efficiency gap (Andrews and Johnson 2016; Backlund et al. 2012; Saunders et al. 2021, 143). This is problematic in that informed management practices are proving critical to energy efficiency, especially in SMEs (Hampton, 2019). On the basis of a literature review in the context of manufacturing firms, Solnørdal & Foss (2018, 14) find that management and organizational factors have "the greatest direct effects on energy efficiency improvements". Professional energy management includes different dimensions, such as strategic planning, implementation, controlling, organizational, as well as cultural aspects (Schulze et al. 2016). However, without professional and institutionalised energy management in most SMEs, energy management is rather informal (Sa et al., 2015). Daily practices, values, and the routines of only a few people within firms often shape energy behaviors and consumption (cf. Fawcett & Hampton 2020). Accordingly, Lawrence et al. (2019, 70) broadly define energy management practices as "daily decision-making for activities related to EnM [energy management][...], in contrast to energy-efficiency investment."

In sum, recent research highlights the importance of management practices in SMEs for improving energy efficiency. The fact that energy management in SMEs is often informal, concentrated on one or few persons, and that employees lack required technical skills suggests that solutions for improving energy management in SMEs need to be easily accessible. Moreover, because of a lack of time to pursue energy management, solutions should be implementable with little time expenditure. Finally, with SMEs often lacking information on energy consumption data, costs, and potentials for savings, solutions should improve an SMEs' information base in order for them to take appropriate measures (like adjusting energy behaviors or efficiency investments).

3 Potentials and limitations: the role of innovative, digital technologies

What kind of digital technologies are currently available on the market that enable SMEs to improve energy management practices? And are they viable options for day-to-day business? To answer these questions, a broad technology screening on digital technologies for SMEs was conducted. The technology screening highlights that a wide range of digital technologies are available, addressing energy efficiency and energy management. However, taking the specific demands of SMEs into account, the market only offers a few suitable solutions which are often niche products and marketed accordingly.

In a first step, on the basis of the technology screening, six technology categories were identified, covering in total 20 systems that are currently available on the markets (cf. Figure 1). On the one hand, *energy monitoring systems, smart metering* and *intelligent energy management systems* (left side) belong to the application field of measurement and control technology. Further, *bus-based* and *radio-based "smart home" building automation systems* represent automation technologies and *intelligent lighting systems* that are identified as efficiency technologies (right side). The systems that were assigned to a technology category have an almost identical structure and similar features. However, there are relevant differences (e.g. regarding the range of functions and interfaces of the systems).

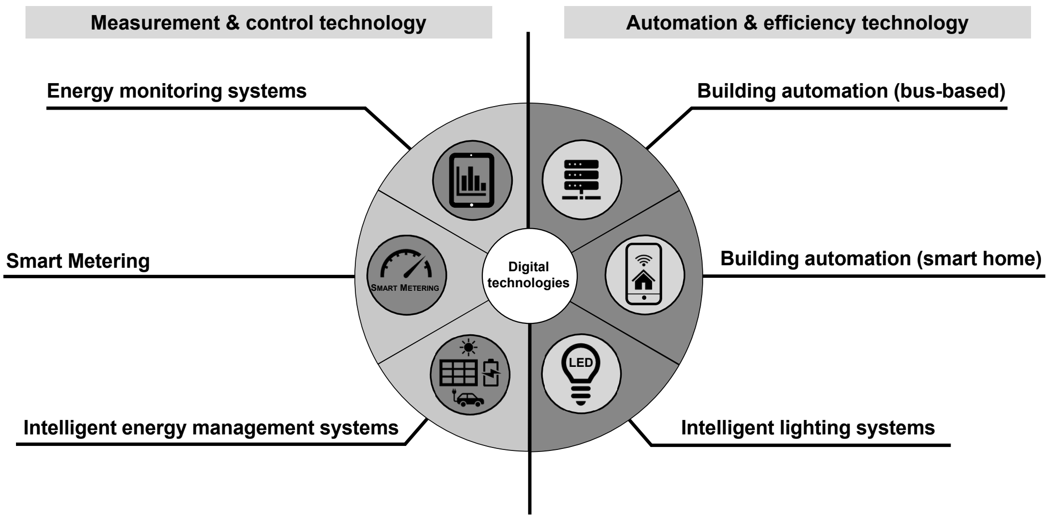

Figure 1: Overview of digital technologies related to energy efficiency and energy management features

In order to identify those digital solutions most suitable for SMEs, several criteria were applied. Firstly, investment costs and low capital availability are economic barriers to energy efficiency investments (Cagno et al. 2013, 297). Thus, new digital solutions should provide a good cost/benefit-ratio; that is, investment volume should be rather low while the potential for improving energy efficiency and energy management practices should be high. Secondly, installation complexity should be low. As personnel in SMEs often lack the time and technical skills to consider energy efficiency opportunities (Fawcett & Hampton 2020, 2; Cagno et al. 2013, 298), it can be assumed that the same holds true for implementing new energy efficiency measures and management practices. Therefore, new digital technologies should generally be compatible with existing infrastructures and easy to apply.

The technology screening was thus done with the following criteria:

1. Adequate cost / benefit-ratio: low investment volume to overcome SMEs investment barrier and energy efficiency / energy management features that address a clear benefit
   (a) *energy efficiency potential*
   (b) *energy and load management potential*
   (c) *costs*
2. Low installation workload: good retrofitting capability and minimal effort for the installation process, as these aspects affect decision making and implementation processes
   (a) *general applicability in SME*
   (b) *compatibility and interfaces*

Two technology categories are identified as being the most promising:[1] *Smart Metering* and *energy monitoring systems* (EMS). Smart Metering achieved the highest scoring among all technology categories of the screening, followed by EMS.

Smart Metering enables digitalized measurement, determination and control of energy consumption and supply. In Germany, smart meters are narrowly defined by law as stationary systems with specific data security requirements and a defined set of infrastructure, interfaces and features (primarily for accounting purposes). In contrast, the technology category *energy monitoring systems* includes a broader range of technologies. Although similar to smart meters in that they enable measurement, determination and visualization of energy consumption, the category includes both mobile and stationary systems. Furthermore, because *energy monitoring systems* are not regulated like smart meters, they can enable submetering, and they are usually developed for professional energy management.

Smart Meters perform well in all considered criteria. Specifically, they offer a very good cost/benefit-ratio and several benefits to SMEs regarding energy efficiency and energy management potentials. Most importantly, they enable energy data visualization via measurements of electricity and heat energy consumption, allowing an analysis of the enterprise's energetic condition. SMEs often lack general data on energy flows and consumption (Janda et al., 2014), which results in a limited understanding of energy costs and in SME underestimating the savings potential of efficiency investments (Mickovic & Wouters 2020, 23). Accordingly, data collection and visualization are key for improving energy management in SMEs. Moreover, in the near future, intelligent metering systems will also offer active control of energy production units as well as electrical consumers and enable time-variable tariffs. Further, the system infrastructure will allow for new energy efficiency services such as benchmarking and predictive maintenance. Finally, costs for Smart Meters are regulated by law via fixed price limits, ensuring limited costs for SMEs.

Regarding criteria for low installation workload, Smart Meters perform well, too. In Germany, the smart-meter-rollout is a strong external political driver for energy efficiency

1 Details about the evaluation methodology and results of the technology screening are published in the final report of the research project "Smart technologies for enterprises" from 2022. The screening does not claim to be exhaustive in terms of representing all technologies available on the markets.

in SMEs. Metering operators are now obliged to install Smart Meters according to the rollout plan, which is defined by law[2]. Since the rollout of Smart Meters is strongly regulated by the government, compatibility is secured by multiple common interfaces. However, the strong regulations and a lengthy certification process delayed the start of the smart-meter-rollout in Germany, which initially should have started in 2017. Even in 2022, there is only a limited number of systems installed in the field (EY 2021).

Compared to Smart Meters, *EMS* cover measurement features including energy data collection, analysis, and visualization based on a submetering approach. The submetering[3] approach allows disaggregating the consumption structure (e.g. electricity consumption) in a more detailed way than just measuring the total consumption with a smart meter. This allows detailed analyses regarding peak and base loads, enables identifying inefficient consumption developing more specific benchmarks. Thus, the use of EMS to collect, analyse and evaluate data on electricity and heat consumption as well as specific consumption groups is the first step towards identifying potential energy savings. Further, EMS are scalable from mobile measurement cases (lower investment volume and installation workload) to stationary systems as a part of certified energy management systems (higher investment volume and installation workload). The following table compares the features of Smart Meters with EMS and lists potentials for SMEs (cf. Table 1).

	Features	Potentials
Smart Meters	Measurement & energy data visualization (via smart meter) Flexible consumption and tariffs Active control of energy production units and consumers (via control box)	Identify potential for peak load shaving and base load reduction Energy cost savings through use of flexible tariffs Energy savings through optimization of energy flows (production and consumption)
Energy monitoring systems (EMS)	Measurement & energy data visualization (via submetering)	Disaggregate consumption structure and identify inefficient consumers Identify potential for peak load shaving and base load reduction on sub-sectional level Create specific benchmarks and enable energetic comparisons

Table 1: Features and potentials of Smart Meters and EMS

On the basis of Smart Meters and EMS, four digitally driven energy management practices were identified and analysed in detail. The following table provides a summary and comparison of Smart Meters and EMS in terms of their potential to enable each energy management practice (Table 2). Specifically, the table shows that both systems are promising digital technologies for improving energy management practices. Yet, owners or personnel will have to understand and make proper use of the new opportunities. Thus,

2 Messstellenbetriebsgesetz (MsBG).

3 Submetering: Measurement of specific sub-distributions and even single consumers (e.g. in an electrical distribution system).

the following two case studies investigate potentials, limitations and barriers to digitally driven energy management in practice.

Energy management practice	Potentials	
	Smart Meters	Energy monitoring systems (EMS)
Peak load analysis	Identification of annual peak loads and definition of measures to reduce peak loads	Identification of consumers responsible for peak loads and definition of specific measures to reduce peak loads
Base load analysis	Visualization of total base load consumption and definition of measures to reduce base load consumption	Identification of consumers responsible for the base load and definition of specific measures to reduce base load consumption
Benchmarking	Development of energy performance indicators in order to compare the energetic condition and efficiency between locations or within a branch	Development of consumer-specific energy performance indicators in order to compare the energetic condition and efficiency between locations or within a branch
Consumption disaggregation	-	Identification inefficient consumers or applications and definition of specific measures to reduce avoidable consumption

Table 2: Digitally driven energy management practices and their potentials based on Smart Meters and energy monitoring systems

4 Field study

The presentation of the cases and results is structured as follows: firstly, the methodological approach is explained. Secondly, each energy management practice is investigated in praxis. That is, on the basis of the field trials, efficiency potentials and limitations are highlighted. Additionally, potentials and barriers from the perspective of SMEs' personnel are identified.

4.1 Methodology

To explore and compare potentials, limitations, and barriers in the context of Smart Meters and mobile EMS for improving energy management practices and implementing energy efficiency strategies in SMEs, two qualitative socio-technical in-depth field trials were conducted. The field trials included energy efficiency analyses of two SMEs based on digital approaches and tools. Additionally, qualitative interviews were conducted. More precisely, Yin (2014, 29) defines five components of case study research design, from a case study's question to criteria for interpreting the findings. The case study's **research questions** are, firstly, "*How can SMEs profit from the benefits of new digital opportunities (Smart Meters* *and EMS) in practice (potentials)"*, and, secondly, "*Why can or can't they (barriers, limitations)?"* The **case study's three main propositions** are, *firstly*, that Smart Meters and mobile EMS enable SMEs to pursue new energy management practices; *secondly*, that this is the case even if personnel responsible for energy management already have high awareness for energy efficiency; *thirdly*, that a fundamental potential and / or barrier for pursuing the new energy management practices is how accessible and interpretable energy data is, and how easy to implement said new energy management practices are.

The **unit of analysis** are persons responsible for energy management in two different SMEs equipped with Smart Meter visualization and mobile EMS. In order to capture a broad range of potentials, issues and fundamental barriers to data driven energy management practices in SMEs, two starkly contrasting SMEs with regard to their electricity system, power needs and related load profiles are included. Consequently, they differ in terms of requirements for energy analysis. The *first case study* covers a recreational company with various types of consumption areas (e.g. restaurant, snack, sales-, living-, office area). The *second case study* deals with the food retail sector, including energy analysis and benchmarking of three grocery stores[4]. Both cases are a "hard test" for the actual energy management potential of the energetic analysis due to the owners' high level of awareness regarding energy related topics. In both cases, owners consider energy costs to be very important for their business. Over the last decade, they have made several investments (e.g. new refrigerators and cooling systems) which reduced their energy consumption significantly. In the case of new investments, care is taken to ensure that the technologies are energy efficient. Thus, both cases can highlight the added value of data driven energy management practices for SMEs that already consider energy efficiency in the context of investment decisions. Finally, both SMEs included do not have any professional energy management, which is typical for SMEs (cf. Fawcett & Hampton 2020, 2).

In order to explore the research questions, two **sources of data** were included.

- *Firstly*, both SMEs were equipped with Smart Meter visualization and EMS. More precisely, in order to better understand the actual benefits of Smart Metering in SMEs, a visualization tool (dashboard) was developed, displaying the total power consumption of recent years with a high time resolution (15min). The tool ("VISEABLE") enables to easily identify peak consumption patterns as well as base loads (on off-days). Further, the consumption data is visualised in various interactive graphics, allowing users a closer look at aggregated data such as daily, weekly, and monthly power consumption, or statistical data concerning consumption patterns. Thus, "VISEABLE" includes features of energy data visualization software used in the context of Smart Metering. Additionally, a mobile EMS was temporarily installed, allowing the analysis of energy consumption data of sub-distributions and specific consumers (e.g. a refrigeration-system in a supermarket) based on a submetering approach. Because of the specific demands of SMEs (cf. chs. 2 & 3), a mobile EMS was used to conduct short-term measurements for up to three weeks using a generic measurement concept (Hilger and Schneiders 2020). The concept includes energy data collection, validation, and evaluation and has been further developed in terms of simplification and efficiency throughout the

4 The three stores belong to a large retail chain, but the operating and organization is managed by a single entrepreneur. Accordingly, the structure is similar to SME in terms of employees and annual balance sum.

field trials (e.g. regarding time requirement). On this basis, the "objective" or rather technical potentials of the technologies and respective energy management practices were investigated; that is, a mobile EMS and Smart Metering based energy analysis of both SMEs was conducted. This allows for identifying the theoretical potential of Smart Metering visualization and mobile EMS for SMEs.

- *Secondly*, a series of qualitative in-depth interviews with the personnel responsible for energy management was conducted. The interviews captured their attitudes, perceptions, knowledge, and behaviors as well as their understanding of the newly provided data driven energy management information. The interviews highlight barriers to digitally driven energy and cost reduction in practice.

4.2 Peak load analysis

The analysis and reduction of peak loads is particularly important in terms of energy cost savings. Enterprises with an electricity consumption of more than 100.000 kWh/a are charged with both a commodity price (€/kWh) and a capacity charge (€/kW). As the capacity charge is calculated by the highest peak load of the annual energy consumption, peak loads directly impact the energy bill. The first case study covering the recreational company highlights the impact of peak loads on energy costs: In 2018, a new ride was installed at the site of the enterprise. Due to a high electricity consumption of the new ride, the peak load increased by factor three compared to 2016. Considering a capacity charge of 80 €/kW, this results in additional annual energy costs of about 30,000 €. Thus, reducing peak loads can reduce energy costs profoundly.

The visualization tool "VISEABLE" displayed the total electricity consumption in both field trials. VISEABLE allows one to determine annual maximum peak loads in terms of energy consumption, date, and time. At the recreational organization, based on the visualization tool, the owner was able to relate the annual peak loads to a summer event. In addition to the visualization tool, the use of the mobile EMS provided a more detailed basis to analyse peak loads, as several sub-distributions and even single electrical consumers were measured in a submetering approach. This allows identifying electrical consumers responsible for peak loads and the definition of appropriate measures to avoid peak loads. Regarding the recreational organization, the detailed analysis based on the submetering approach indicated that the annual peak loads can be allocated to the sub-distributions "Restaurant" and "Camping site". However, the owner stressed the importance of the summer event and was not able to identify measures addressing peak loads in "Restaurant" and "Camping site".

In the case of the three grocery stores, it was possible to identify relevant measures for substantial peak load reduction. The visualization tool enabled the owner to "capture the peak load issue on the fly." Two stores' peak loads occurred on the exact same hot summer day during the midday hours. In contrast, the third store had a lower peak on a different day and early in the morning. The discrepancy between the stores is that the latter has a PV system installed, whereas the former two do not. Thus, based on consultation and data visualization, the owner became aware of and understood the relevance of PV systems for peak load reduction in the context of his grocery stores. He decided to invest in PV systems for the other two stores. Furthermore, calculations of the amortisation periods for the new PV systems now also included the positive effect on peak load reduction.

4.3 Base load analysis

Similar to reducing peak loads, there's a strong economic incentive to reduce base load consumption. As the base load is defined as the permanent minimum load in electric power systems, it appears over the whole year (8,760h). Thus, assuming a common electricity price for the commercial sector of 0.21 ct/kWh, a reduction of 1 kW results in annual energy savings of 8,760 kWh and annual energy cost savings of approx. 1,840 €. Server rooms, refrigeration systems or standby consumption are just a few examples of a typical base load consumption. Yet, without data collection and visualization, owners of SMEs have no knowledge about their base load.

In the field trials, the visualization tool provided annual average values of the base load consumption and displayed daily load profiles. Figure 2 (left chart) shows an example of a daily load profile based on data from the recreational company. The firm's base load consumption, that is, electricity consumption during the non-operating hours of the enterprise between 10^{pm} and 7^{am}, is displayed. Moreover, information on the total amount and the temporal changes of the base load can be derived. By measuring several sub-distributions in parallel, the submetering approach using the mobile EMS enables disaggregating the base load (ct. Figure 2, right chart). With this data, the specific base load in each sub-distribution and its percentage share on the total base load can be analysed, providing a sound basis to identify potentials for reducing base load consumption.

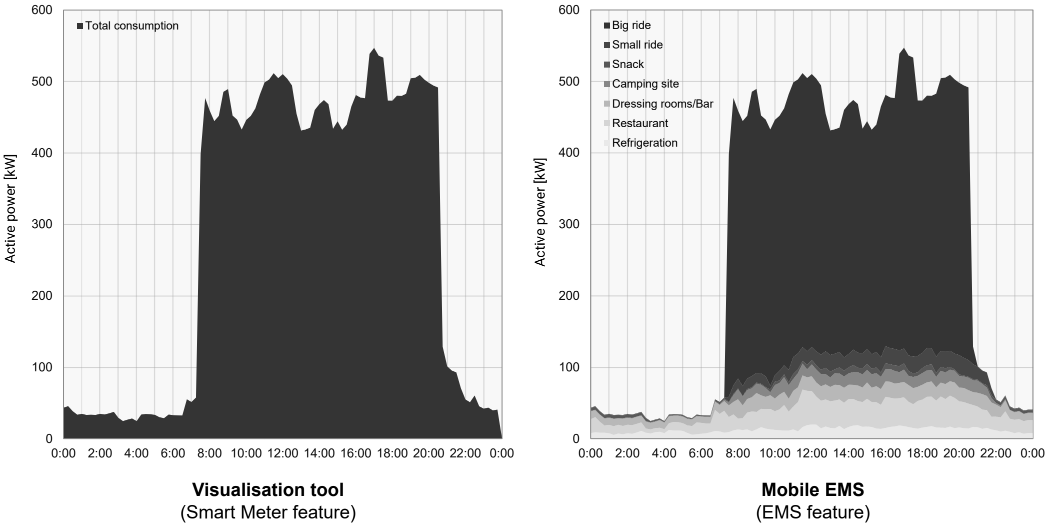

Figure 2: Comparison of a daily load profile based on data from the visualization tool and the mobile EMS

In both cases, owners and personnel were not aware of base loads and its impact on energy costs and consumption. According to the electrician of the recreational company, the analysis and consultation helped "to really realise such facts first of all". On the basis of VISEABLE and the detailed analyses with the mobile EMS, the electrician was able to identify the base load. Discovering a 10 kW base load in a sub-distribution via submetering, "[..] you ask yourself: 'How can that be?' What do you then do with it?

You then have the opportunity to take a closer look. But that takes some time." Thus, the visualization tool and submetering enabled owners and personnel to add base load analysis and reduction to their energy management practices.

4.4 Benchmarking

Benchmarking is a data driven energy management practice, enabling the energetic comparison of one or several locations of an enterprise to standardised average values in specific branches. First, energy performance indicators (EnPIs) are defined, relating the energy consumption of an enterprise or specific electrical consumers to operating values (e.g. sales area (m^2), number of customers). Second, based on the comparison of EnPIs, inefficiencies regarding energy consumption are identified, allowing to implement energy efficiency strategies and measures.

In the field trials, EnPIs based on the total annual energy consumption (electricity and heat consumption) and sales area were defined (ct. Figure 3), representing a potential feature of the visualization tool and appropriate Smart Metering visualization software. On this basis, the three stores were benchmarked in terms of their energetic condition, including a comparison to literature values of the food retail sector (EHI Retail Institute 2019). Despite the good energetic condition of the three stores, the interpretation of EnPIs based on annual energy consumption indicated energetic differences regarding the buildings' technical equipment (e.g. ventilation systems with / without heat recovery system). In this specific case, the higher EnPI of store C compared to stores A, B, and the branch benchmark could be pinpointed to an additional gas boiler. This system has already been replaced by a modern heat-recovery system in stores A and B (cf. Hilger et al. 2020).

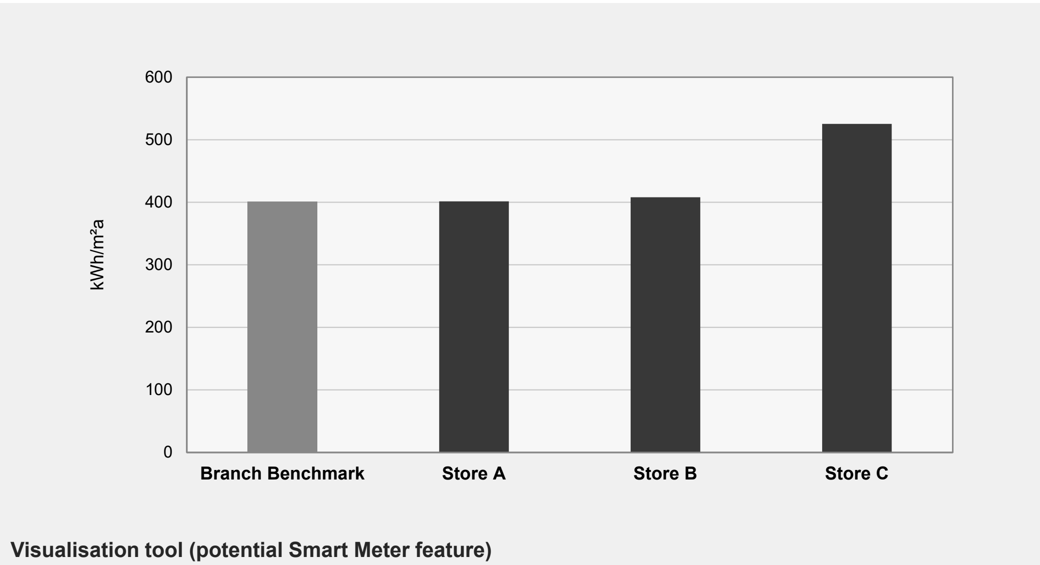

Figure 3: Comparison of the three stores' EnPIs based on total annual energy consumption and sales area with the branch benchmark for the food retail sector

However, as the total electricity consumption of an enterprise contains a mix of different devices, these EnPIs do not reveal any information regarding single consumption groups (e.g. refrigeration system). Thus, measuring single consumption groups such as refrigeration systems or ventilation systems with the mobile EMS enables defining consumer-specific EnPIs (ct. Figure 4). These EnPIs are based on the electricity consumption data of a reference week, but can be scaled up to cover annual consumption. As consumer-specific EnPIs enable the energetic comparison on the level of consumption groups, they ensure a more detailed interpretation and analysis of the energetic condition. Yet, reference values to consumer-specific EnPIs are still missing in literature (Hilger et al. 2020).

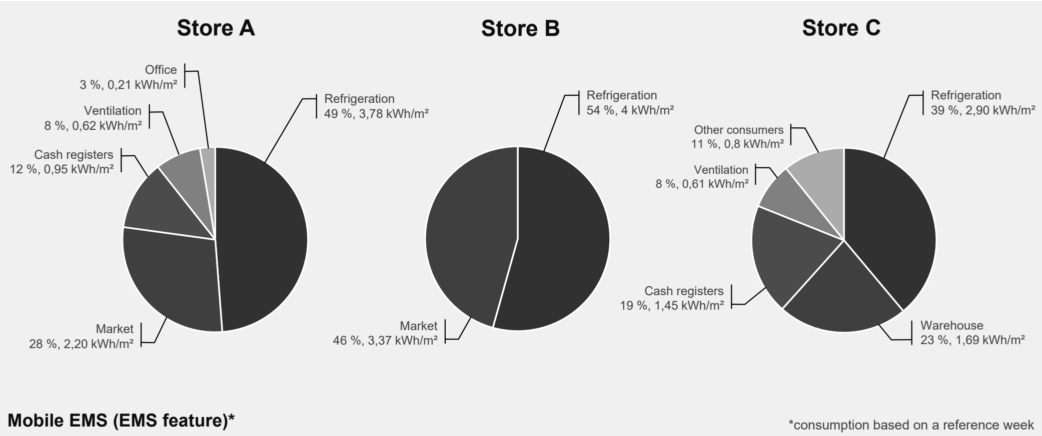

Figure 4: Consumption disaggregation and consumer-specific EnPIs per m² sales area based on the mobile EMS

Despite the owners' high problem awareness concerning energy related topics, results of the interviews indicate that extensive guidance is necessary for owners or personnel to fully comprehend and interpret EnPIs as well as to draw direct conclusions from them (e.g. energy efficiency strategies). For benchmarking, it is also a precondition that SMEs either have access to relevant reference values (for example kWh/m²) or that they have several branches in order to compare different results. Thus, benchmarking places higher demands on the owners' competence and knowledge compared to peak and base load analyses. Additionally, contextual competence and knowledge is required to establish benchmarking as an energy management practice in SMEs.

4.5 Consumption Disaggregation

In addition to consumer-specific benchmarking, Figure 4 also illustrates the energy management practice "consumption disaggregation" based on short-term measurements in the three grocery stores. Thus, the percentage share of each sub-distribution on the total electricity consumption is calculated and displayed in the Figure. Further, the submetering measurement data provided a basis to identify patterns and anomalies in the load profiles of each sub-distribution and consumption group (e.g. refrigeration system, ventilation system, market, etc.). Based on these analyses, inefficient electrical consumers, which otherwise would have remained undetected, were identified in the field trials. In the case of the recreational company, based on the detailed analyses and submetering, two outdated engines were identified as very energy inefficient, which was very valuable from the owner's perspective.

However, consumption disaggregation based on measurement data requires more time and effort (e.g. conduction and evaluation of short-term measurements). This is why mobile EMS are rarely used in the context of energy audits. Consultants prefer to use projection methods to disaggregate the consumption structure (Hein, Mischo, and Hofmann 2018). Nevertheless, results of the field study indicate that, if a mobile EMS is used according to a systematic measurement concept, the analyses of submetering data can provide substantial benefits to promote energy management practices and efficiency strategies in SME.

Summing up, consumption disaggregation clearly addresses the potential to identify inefficient power consumption, thus providing a solid basis to implement energy efficiency measures. Yet, the implementation of measurements and the evaluation of energy consumption data is more complex, pointing to limitations regarding time and effort.

5 Results

Results indicate compelling potential for improving SMEs' energy management practices on the basis of Smart Metering visualization and mobile EMS, but also point to barriers in practice. The energy management practices of *peak load analysis*, *base load analysis*, *benchmarking*, and *consumption disaggregation* enable SMEs with different electricity systems, power needs, and related load profiles to profit from energy and cost reductions. Data collection and visualization greatly improves SMEs' knowledge of basic or even more detailed energy consumption patterns, which SMEs are often lacking (Mickovic & Wouters 2020, 23). Yet, lacking the knowledge of energy management practices and in some instances the need for more complex analyses poses relevant barriers. Additionally, the time necessary to pursue the different practices differs and also depends on a SME's specific circumstances. More precisely, the following adoption model illustrates the necessary steps for establishing digitally enabled energy management practices (5). Potentials and barriers to every step in the adoption process are explained below and illustrated on the basis of the case studies. Due to the exploratory research design, hypotheses for future research and policy implications are also presented in this results section.

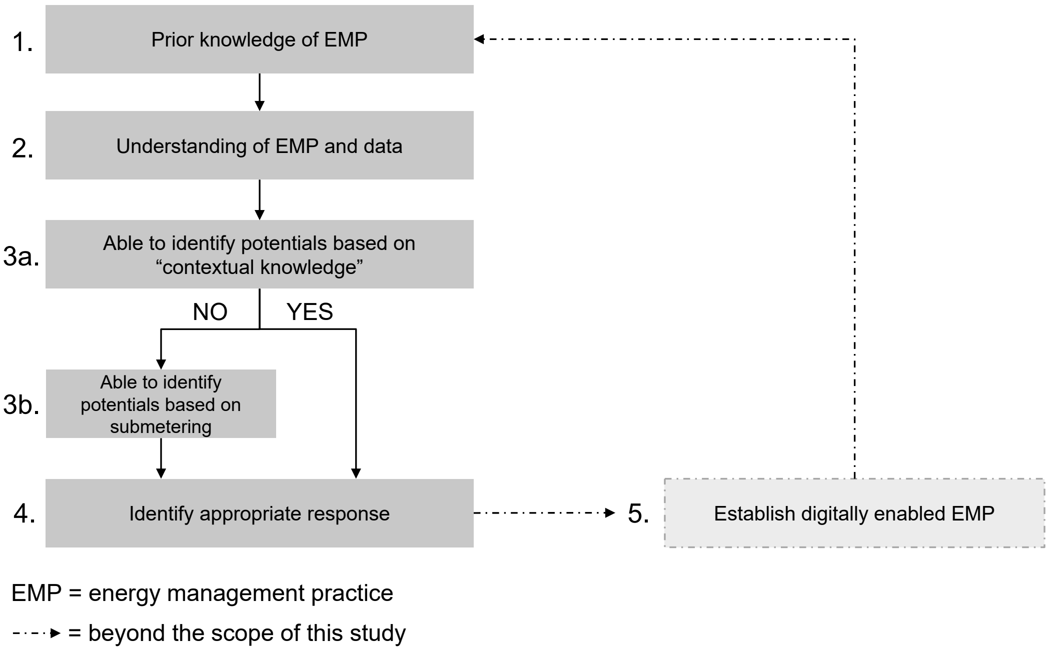

Figure 5: Adoption model for establishing digitally enabled energy management practices

(1.) **Prior Knowledge:** Owners and personnel did not have prior knowledge of any of the digitally enabled energy management practices. Although owners in both cases consider energy costs to be very relevant and they take energy efficiency into account when making investment decisions, they were not familiar with data driven energy management. Since it is not usual for SMEs to have access to smart meter data or submetering data, it can be assumed that personnel or owners are also not aware of digitally enabled energy management practices. Both cases reinforced this assumption, indicating a fundamental barrier to adopting respective practices.

Hypothesis 1: Equipping SMEs with smart meters alone will not be sufficient to establish digitally driven energy management practices. Owners need to be educated about the possibilities of data driven energy management.

Policy implications: In order to educate owners of SMEs, introduction to data driven energy management practices should be an integral part of the smart-meter-rollout.

(2.) **Understanding of energy management practices and data:** On the basis of consultations, owners were able to understand which data was relevant for the respective management practice and why the management practices are helpful for reducing energy consumption and costs. Consequently, the case studies' results suggest that, with adequate consultation, a lack of understanding of the digitally enabled practices can be overcome. However, the owners already had a good understanding of energy related topics in both cases, which could explain why they were able to easily understand the new practices.

Hypothesis 2: Owners with a generally good understanding of energy related topics are able to easily understand the new energy management practices and related data.

Hypothesis 3: Business owners without a generally good understanding of energy related topics are challenged to easily understand the new energy management practices and related data, indicating a fundamental barrier to adoption.

(3a.) **Able to identify potentials based on "contextual knowledge":** A key question for the success of Smart Metering visualization is, if owners or personnel are capable of identifying potentials based on "contextual knowledge". When analysing peak loads, e.g., the first question to ask is why the peak loads occurred and if owners are able to relate the peaks to specific events and / or electrical consumers. In the case of the grocery stores, the owner was able to identify hot weather conditions as the reason for the peaks in the two stores without a PV system. He understood the positive impact of the PV system installed in the third store (cf. ch. 4). With the recreational company, owners were also able to relate peak loads to a specific summer event. This kind of contextual knowledge thus enables owners to understand and to identify potentials for improvement. However, contextual knowledge is not always sufficient to identify inefficiencies. Only very detailed submetering enabled identifying a very inefficient electrical consumer with the recreational company.

Hypothesis 4: Contextual knowledge is vital for owners to identify potentials for optimization on the basis of data visualization.

Hypothesis 5: In case contextual knowledge is not sufficient to identify potentials for optimization, mobile submetering is necessary.

(3b.) **Able to identify potentials based on submetering:** Results indicate that especially in cases where contextual knowledge is not sufficient, submetering substantially increases the possibilities for discovering energy and cost consumption reductions. With most SMEs lacking stationary submetering, mobile EMS provides a less costly alternative. Results of this case study indicate that mobile EMS can improve all of the energy management practices and is especially relevant for identifying inefficient consumption and for enabling more detailed benchmarking. However, in comparison to Smart Metering visualization, pursuing energy management practices based on submetering takes more time and effort, which is generally a barrier to energy efficiency in SMEs (cf. Fawcett & Hampton 2020, 2). While SMEs in Germany will now be equipped with smart meters, the same does not apply for EMS, leading to higher costs for adopting mobile EMS. Additionally, more encompassing external consultation and implementation are necessary compared to Smart Metering visualization. Yet, in the case of the recreational company, mobile EMS enabled identifying excessive energy consumption and thus provided fiscal benefits for the company. With the grocery stores, which are mostly similarly structured, EMS proved to be especially beneficial for benchmarking. Due to the fact that mobile EMS has to be conducted by external consultants, it is less important for owners or personnel to be able to identify optimization potentials by themselves.

Hypothesis 6: Mobile EMS is an appropriate solution for SMEs and offers high potentials for identifying inefficiencies.

Hypothesis 7: Mobile EMS is less depended on personnel's contextual knowledge in order to identify optimization potentials.

Hypothesis 8: Lack of awareness as well as the costs, and effort involved are serious barriers to adopting mobile EMS and external consultation.

Policy implication: Due to the substantial optimization potentials and reduced costs compared to stationary submetering, governmental energy efficiency programs should include data-based auditing with mobile EMS.

Policy implication: Energy efficiency auditing is not data driven. Thus, mobile EMS should be included in order to fundamentally improve the quality of energy efficiency auditing.

(4.) **Identify appropriate response (e.g. behavioral adjustments / implement measures / investments):** It was crucial that the owners understood the energy management practice and identified potentials for energy and cost saving measures (with or without consultation). On this basis, they were able to consider appropriate responses and efficiency measures. More precisely, when provided with the relevant data on the one hand, and the specifics of the energy management practice on the other hand (e.g. the relevance of base load for costs and consumption), owners were able to identify measures and calculate to some extent benefits for investment decisions. Therefore, the cases indicate that developing appropriate responses as well as taking SMEs' business model and clientele into account, is not an insurmountable barrier to improving energy efficiency in SMEs.

Hypothesis 9: When provided with relevant data and information on optimization potentials, owners of SMEs are capable of developing appropriate responses.

(5.) **Establish digitally enabled energy management practices:** Energy management practices should continuously improve energy efficiency in SMEs. Digital solutions like Smart Metering and mobile EMS enable data driven energy management practices. Thus, establishing data driven practices will be vital for successfully improving energy related behaviors in SMEs. However, the medium and long-term establishment of digitally driven energy management practices was not examined as part of this study. Future research should thus investigate longer time frames after the initial implementation of Smart Metering or mobile EMS.

6 Conclusion

The aim of this field trial study is to explore the potentials of and barriers to digitally enabled energy management practices in SMEs. In a first step, using technology screening, this study identified Smart Metering and energy monitoring systems (EMS) as digital technologies best addressing SMEs' specific demands. In a second step, two qualitative in-depth field trials were conducted to explore the technologies' potentials, limitations, and barriers in practice. The results indicate that Smart Meter visualization and mobile EMS enable SMEs to pursue new energy management practices. More precisely, owners were able to conduct peak load analysis, base load analysis, identify inefficient devices, and conduct benchmarking. All these data management practices provided substantial cost and energy consumption reduction for both SMEs. However, the exploratory study results suggest that only equipping SMEs e.g. with smart meters will not be sufficient. Owners will have to be educated about data driven energy management practices and corresponding benefits. Owners need clear, easily accessible and already prepared information on digitally enabled energy management practices (like peak and base loads). Moreover, mobile EMS and consultation offers substantial benefits in terms of in-depth energetic analyses (e.g. consumer-specific benchmarking, base load reduction, identification of inefficient consumption, context-dependent optimal measures) compared to stationary smart metering. Based on an exploratory adoption model, this study suggests steps necessary to establish digitally enabled energy management practices in SMEs. Hypotheses were derived to be explored in future experimental studies. In particular, it will be necessary to investigate to what extent smart meter software can provide features enabling said energy management practices without consultation, or if mobile EMS with consultation is in the end more cost efficient than only stationary smart metering.

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This work was supported by the European Regional Development Fund [grant number EFRE-0600038].