Energy efficiency analysis and benchmark in grocery stores: Results of a short-term sub-metering measurement campaign

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ABSTRACT

The objective of this research is to create a methodical approach for the energetic analysis and comparison of grocery stores using a mobile measurement-system in on-site investigations. Altough energy measurement technology is a useful tool for the structured analysis of enterprises, there's little research on benchmarking analyses based on energetic data from a mobile measurement-system. In this context, this study analyses three grocery stores (supermarkets) focusing the energetic comparison and determination of energy performance indicators (EnPIs). This research found that the energetic data of the measurements on a sub-sectional level provide relevant data for a benchmarking-system and the determination of EnPIs. The scientific approach outlined in this work aims the quantification of energy saving potential and energy benchmarking analyses and shall be transferable to enterprises in any industry.

KEYWORDS

energy efficiency, energy saving potential, grocery stores, benchmarking analysis, sub-metering, data collection, data analysis, retail sector

INTRODUCTION

Due to the guidelines of the EU energy efficiency directive (*2012/27/EU*) as well as prospectively increasing energy costs (*EU Energy Outlook 2040*) the energy efficiency topic gets more important than ever before [1]. Especially in the industry sector and the sector of commerce, trade and services, where the energy consumption is respectively high, the efficient usage of energy has become a competitive factor in recent years [2]. In addition, improving energy efficiency has become one of the major goals of the EU climate change policy. In order to meet the climate objectives of the European Union (reducing primary/final energy consumption by 32.5% until 2030), governments have to take action in the field of renewable energy and energy efficiency [3].

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In a German context, the government has recently (December 2019) published its energy efficiency strategy 2050 (*EffStra 2050*) in order to meet the new EU guidelines. Therein, a reduction of 30% primary energy consumption until 2030 (to 2008) is defined as Germanys new national energy efficiency goal. For the consumers in the domestic sector, the industry sector and the services sector measurements to reduce primary energy consumption in the amount of 500TWh are scheduled. Therefore, further efforts in energy efficiency are anticipated for the next years [3].

Research studies analysing the energy efficiency potential in the industry and services sector, such as *IREES (2013)* [4] and *PwC (2015)* [5], state especially a high potential in small and medium-sized enterprises (SME[†]). According to the PwC study more than one third of the SME could reduce their energy costs through an investment in energy efficiency measurements by at least 20% [5]. The fact that SME make up about 99.5% of all enterprises in Germany underlines the high overall energy efficiency potential in these enterprises [6]. Besides the entrepreneurs lack of time and knowledge about energy efficiency in general, current research also highlights that smaller enterprises do not see the chances in digital, smart technologies in order to increase energy efficiency [7, 8].

Previous research analysing the usage of smart technologies such as energy monitoring-systems, intelligent metering-systems or intelligent lighting in SME has shown that these technologies are used in only isolated cases. Onsite investigations in SME pointed out that the energy flows are often unknown. Furthermore, measurement technology is not yet installed and even the energy consumption data from the regional utility company have not yet been analysed by the enterprises [9]. Due to the importance of "energy transparency" as a basis for the quantification of the energy efficiency potential in enterprises ([9–11]), the systematic and structured efficiency analysis of SME through the usage of a mobile measurement-system has been developed as the first approach for increasing the energy efficiency in SME (research project "*Smart Technologies for Enterprises*"). A methodical concept using the mobile measurement-system as well as first results of the added value are outlined in [12]. The elevation of electricity consumption-data of sub-sections of an SME allows a deeper analysis of the enterprises' energetic condition. Furthermore, it enables potential for benchmarking analyses, since energetic data on the consumer level is available through the mobile measurement-system [12]. The mobile measurement-system applied in the application tests in SME is specialised on the measurement of the effective power, since the measurement of heat power is far more complex [11]. As a particular feature, the measurement-system is able to ensure a parallel measurement of up to six sub-sections of the enterprise, in order to guarantee a fast transparency of energy flows [12].

The current literature on energy benchmarking-systems and the identification of relevant energy performance indicators (EnPIs) show that several studies have been carried out depicting benchmark values for specific industries [13, 14]. Especially *Schreckenberg (2018)* points out a research gap on energy efficiency benchmarking, since current benchmark values are based on a superficial level [15]. Specific benchmark values on a sub-metering level (e.g. for refrigeration-systems) do not yet exist according to the literature review [13–15].

In this context, the aim of this research is to analyse the applicability of the mobile measurement-system as a tool for an energy efficiency analysis with a focus on its benefit and added value for energy benchmark aspects. We do this by conducting an energy efficiency analysis in three grocery stores using the mobile measurement-system in order to bring transparency into

[†]Small and medium-sized enterprises (SME) are defined by the EU directive 2003/361/EG by quantitative factors (number of employees (< 250), annual turnover (< 50 M€) and annual balance sum (< 43 M€).

the energy flows. Grocery stores are often stuctured in chains that do not correspond to the SME-definition due to quantitative factors mentioned above. However, the three stores are analysed as isolated sites. The research focuses on a valuation of the energetic condition of each individual store and an energetic comparison of all three stores in the field test to define the energy efficiency potential.

The paper is structured as follows: Background and related research points out the most relevant literature on energy usage, energy efficiency and energy benchmarking in grocery stores. Method describes the applied methodology of the energetic analysis in general as well as methods concerning energy data collection and data analysis. Results presents the final outcome of the energetic analysis and an evaluation of the added value and benefit using a mobile measurement-system for benchmarking analyses. The discussion qualifies the results of the field test with a special issue to benchmarking potential. Finally, Conclusion sums up the main issues of the findings and proposes approaches for future research.

Background and related research

According to the data from the *European Environment Agency* published in January 2020, the services sector is one of the fastest growing sectors in Europe. From 2005 to 2017 the energy consumption of the services sector increased annually by 0.6 % [16]. The retail sector itself represents the largest share of electricity consumption in the services sector and accounts for 30 % of the total electricity consumption [17]. The literature review on current studies analysing the energy usage and energy efficiency in the retail sector (*dena (2016)* [18], *ehi (2017, 2019)* [19, 20]) has shown that these studies distinguish between either food and non-food sections or small scale and large scale retailing. Especially the differentiation between food and non-food is appropriate, since food retailers have the highest specific energy consumption in the sector followed by textile retailers and DIY and furniture stores [17]. According to *dena (2016)*, the non-food sector represents generally speaking about 40 % of the food sectors energy demand. In terms of environmental pollution, the food retail sector accounts for about 1 % of the total greenhouse gas emissions of Germany [21].

On the one hand, this is due to the high electricity consumption of food retail stores. In general, electricity accounts for 74 % and thermal energy for just 26 % of the total energy consumption of retail stores in the food sector [2]. For large-scale retail stores, this ratio focuses even more on electricity consumption (84 % electricity, 16 % thermal energy) [18]. The higher proportion of electricity over other energy sources is typical for food retailers due to the cooling demand for the foods [17]. This is why refrigeration systems have the largest share of electricity consumption in retail stores (food) and are responsible for 46 % of the electricity consumed [19]. Furthermore, lighting-systems (25 %), air-conditioning and ventilation (10 %) as well as other consumers (11 %) including cash register-systems and small decentralised consumers account for the electricity consumption of food retail stores [19].

In recent years, with typically low margins in the trading sector and increased energy costs (e.g. grid usage charge), retailers have started to invest in operational cost-saving strategies [19, 22]. As energy costs are typically the second largest cost for retailers beyond labour, the achievement of sustainability targets (e.g. by implementing energy efficiency measurements) has become more important for retailers [22]. In a German context, retailers reduced their energy costs about 6.4 % in 2014 compared to 2013 [2]. Especially in the food retail sector, the specific energy consumption per m² sales area constantly decreased in the last four years [20]. Generally, these achievements are due to the efforts of food retailers to invest in energy efficiency measurements. A nationwide survey by *ehi Retail Institute (2019)* revealed that 53 % of the food retail chains invested in the last five years more than 25 million € in energy efficiency. Furthermore, retailers renovate on average about 7-10 % of their stores per year, a relatively huge value compared to the residential buildings in Germany [20]. Most investments into energy efficiency measurements are spent on new refrigeration-systems as well as the switch to LED lighting-systems, as these represent the largest consumer groups in retail stores. In 2019, about 64 % of the food retail stores in Germany have already switch to LED lighting-systems and almost 100 % of the refrigeration units are equipped with coverings [20]. The review on related literature has shown that energy efficiency and implementation of energy efficiency measurements are already an important aspect for rood retailers.

The efforts in energy efficiency also positively effect the environmental pollution of retail stores. In recent years, a lot of single, decentralised refrigeration-systems were replaced by compound refrigeration-systems based on carbon dioxide (CO_2) as refrigerant. Whereas refrigeration-sytems based on R134a or R404A produce both direct (by potent greenhouse gases) and indirect (by energy usage) emissions, systems based on natural refrigerants such as CO_2 (R744) almost produce 100 % indirect emissions [21]. This is due to the global warming potential (GWP), which indicates how destructive a climate pollutant is. In general, refrigerants such as R134a have more than 1,000 times the potency of carbon dioxide [23]. Consequently, when it comes to improving the environmental pollution of retail stores equipped with a refrigeration-system based on CO_2, the reduction of indirect emissions (e.g. through reduced use of energy) has to be adressed [21].

While the current status of energy use and energy efficiency in retail stores is described in several studies mentioned above, there's still little research and information on energy benchmarking. Energy benchmarking in general describes the energetic comparison of enterprises or processes within or across industries using energy performance indicators (EnPIs). EnPIs could help enterprises to compare their energy system either to other enterprises within the industry or – especially in the retail sector – within chains. In Germany, several studies (*Ratjen et al. (2013)* [14], *Schreckenberg (2018)* [15]) analysed industry-specific EnPIs based on the final energy consumption or electricity consumption. However, specific EnPIs on the level of cross-sectoral technologies do not yet exist due to the methodical and organisational challenges of implementing a benchmarking system in an enterprise [15]. For the retail sector (esp. food), most EnPIs are related to the stores' sales area (m²). The sales area has a major impact on the stores' energy consumption and is therefore particularly suitable as a reference figure. *Ratjen et al. (2013)* also mentions reference values for EnPIs related to the number of employees [14]. The following table shows EnPIs for the food retail sector based on the literature review of this study (Table 1).

Table 1. Benchmarking values (EnPIs) for the food retail sector based on literature review

EnPI	**Ratjen et al. (2013)[14]***	**Ehi Retail Institute (2019)[20]**	**Dena (2015)**	**Dena (2016)****
Electricity Consumption (kWh) / Sales area (m²)	341	317	358	331
Final Energy Consumption (kWh) / Sales area (m²)	472.8	401	481	396
Electricity Consumption (kWh / Employee ()	14.391	/	/	/

*median values

**for large-scale retail stores

As there is no big gap between the electricity consumption and the final energy consumption related to the sales area, the EnPIs underline that thermal energy has a smaller significance in food retail stores compared to electricity. Further, the latest figures (*Ehi Retail Institute*) are at once the lowest EnPI values based on the literature review. This correlates with current energy efficiency statistics in retail stores, as further measurements were implemented in recent years [20]. The given benchmarking values represent a basis for the energetic comparison of the grocery stores. Moreover, this study determines specific benchmarking values based on the level of cross-sectional technologies with the use of a mobile measurement-system.

METHOD

This study adopted a qualitative approach to empirically identify the benefits and added value using a mobile measurement-system as a tool for the energetic analysis of grocery stores. The general methodology for the energetic analysis of the three stores is based on an approach outlining the systematic energy data collection and evaluation in small and medium-sized enterprises using a mobile measurement-system, published by the authors (*Hilger and Schneiders, 2020*) [12]. *Hein et al*. (2018) [11] describes a similar approach based on the usage of a mobile measurement-system. The following figure gives an overview of the energy data and evaluation process and divides it into five relevant steps (Figure 1).

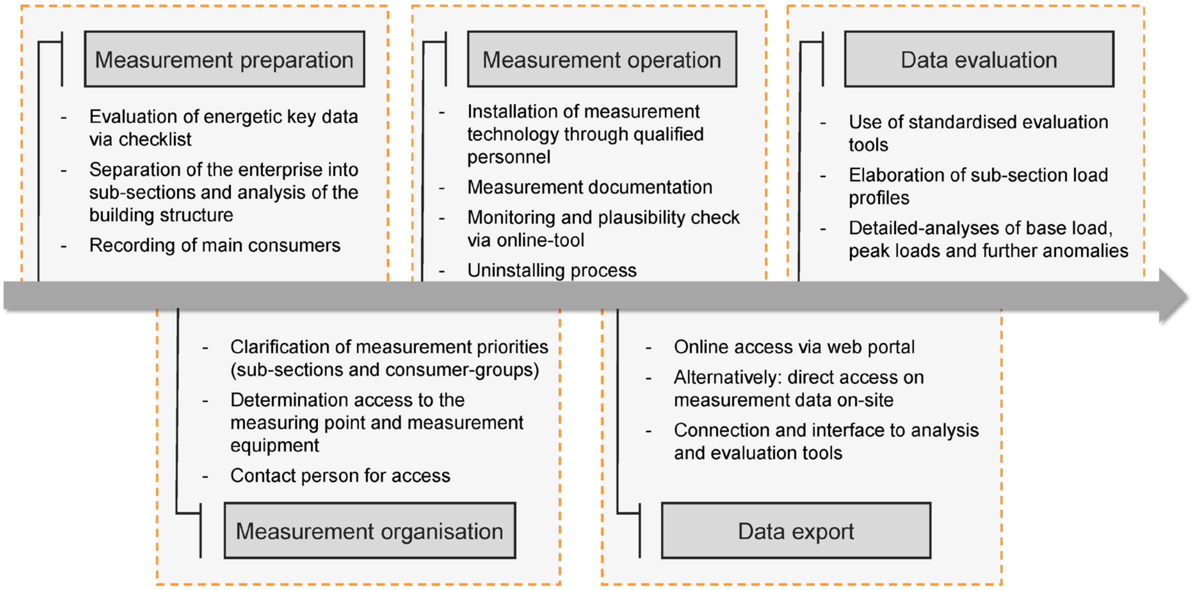

Figure 1. Energy data collection and evaluation process using a mobile measurement-system for electrical power measurements [12]

The given process was developed considering especially the aspect of establishing a systematically structured and simplified approach. Therein, the usage of the mobile measurement-system is structured into the steps measurement preparation (1), measurement organisation (2), measurement operation (3), data export (4) and data evaluation (5) (Figure 1).

Starting with the measurement preparation and organisation, it is important to evaluate energetic key data of the enterprise via checklists. At this point, the building structure as well as relevant sub-sections and consumer groups have to be identified in order to obtain an overview of the enterprises' energy system. Further, information about the structure of the low-voltage main distribution is important to prepare the measurements. Concerning the hardware of the measurement-technology, a mobile measurement-system for electrical power measurements is used. The selected measurement case (*me2go* by *manageE GmbH*) enables the parallel measurement of up to six sub-sections (each with three phases) of the electrical main distribution [24]. This is done by installing current transformers and Rogowski coils at each phase. The phase current induces a secondary current which is transferred to the measurement controller converting the signals into digital data. The voltage is taken from the enterprises' electricity network for each of the three phases. The parallel measurement of up to six sub-sections ensures a fast proceeding to get transparency into the energy flows of an enterprise as well as the quantification of subsequent energy efficiency measurements. Based on findings of various on-site investigations with the mobile measurement-system, the period of the short-term measurements varies between one but no later than two weeks [12]. This also ensures the overall efficiency of the energy data and collection process. As a further technical requirement, a remote access to the measurement data is important for both plausibility checks as well as the subsequent data export. The data export itself can be conducted via the IP-address of the measurement case or a web-based tool with access to an SQL-server. Once the measurement data is exported, it will be prepared, analysed and evaluated in software-tools such as MS EXCEL (2020) or PYTHON™ in different time scales (15min to 1sec). Both load profiles and aggregated data of the measured sub-sections are visualised in these tools. By creating a reference week (Monday to Sunday) based on the short-term measurement, the percentage shares of the sub-sections on the total energy consumption of the reference week can be identified. The analysis of the energetic data provided by the mobile measurement-system allows deeper insights of the enterprises' energy system due to the quantification of sub-sectional energy flows [12].

Approach for a benchmarking analysis in grocery stores

Due to the fact that the measurement-campaign focuses on a benchmarking analysis and the energetic comparison of three grocery stores, the data collection and evaluation process had to be adjusted according to these circumstances. In order to compare the energetic condition of each store with each other, energy performance indicators (EnPIs) are developed based on the energetic data from the utility and the mobile measurement-system. The following figure points out the methodology analysing the three stores in consideration of the benchmarking analysis and the energetic comparison (Figure 2).

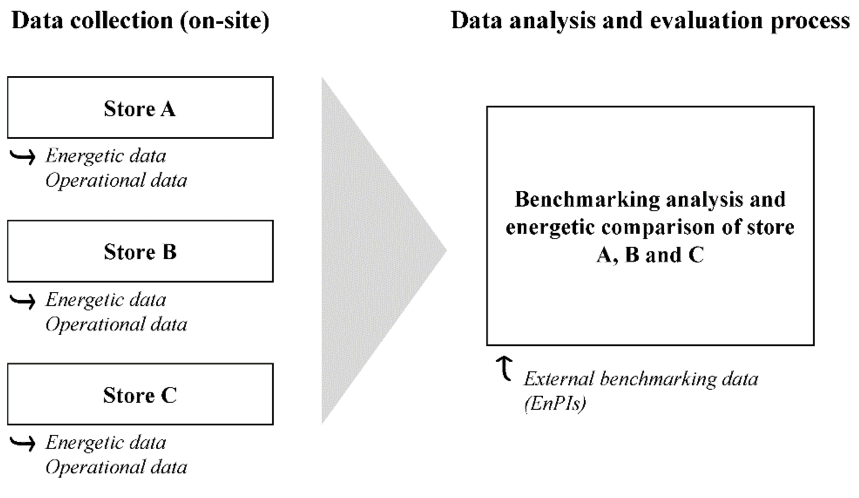

Figure 2. Adjusted methodology for the benchmarking analysis and energetic comparison of three grocery stores

In this measurement-campaign, the energy consumption data (year 2018) from the utility as well as the data from all measured sub-sections represent the basis for the energetic data. The energy consumption of the refrigeration-system has been measured in each individual store. As already described this sub-section has the highest percentage share of each stores' total energy consumption and is therefore especially important for benchmarking analyses. In terms of operating data, literature has shown that the "sales area" (m^2) of each store is suitable as reference value. Furthermore, the "customer numbers" () has been collected as additional reference value, as it is an indicator for the number of products sold. All EnPIs developed in this study are based on the energetic data collected in on-site investigations of the three stores.

The data evaluation within this research includes the analysis of the sub-sections of each store located at its low voltage main distribution. The parallel measurement of different sub-sections allows the evaluation of the percentage share of each sub-section on the stores' total electricity consumption. Finally, a validation between the consumption in each sub-section based on short-term measurements and the total electricity consumption from the previous year (utility data) is done. The short-term measurements were conducted over a time period of 8-13 days per store. Due to the short time-period these measurements are not representative for long-term interpretations and analyses. This is why the energetic data from the utility has to be analysed according to seasonal fluctuations as well. For the measurement campaign, it is important to identify sub-sections that are subjected to these seasonal fluctuations (e.g. a refrigeration-system due to the correlation with the outdoor temperature).

RESULTS

Analysis of the energetic condition and data-evaluation

As described in the previous chapter, all three stores were subjected to a fundamental energetic analysis. The onsite investigations revealed a different structure in each of the three markets, which are presented briefly in the following section. The energetic key data collected in the on-site investigations as well as fundamental environmental data such as indirect CO_2 emissions are presented in the table below (Table 2). In the following sections, the stores are named store A, B and C to ensure a clear identification.

Table 2. Energetic key data of the three grocery stores

	Electricity Consumption (2018) [kWh]	**Energy Costs (2018) [€]**	**CO_2-emissions (2018) [kg_{CO_2}]***	**Sales Area [m²]**	**Customer Numbers (2018) []**
Store A	398,244	77,614	208,282	1,000	528,362
Store B	609,525	116,401	318,782	1,500	682,223
Store C	1,176,883	224,530	615,510	2,709	1,170,640

* Evaluated with the CO_2 emission factor of the German electricity mix (2016): 0,523 kg/kWh [25].

As already mentioned in the previous chapter, the operating data "sales area" and "customer numbers" listed in Table 2 correlate with the energetic data from the utility. Considering all cost components (commodity price, grid usage, etc.), the specific energy costs of the three stores vary between 19.08-19.49 ct/kWh. In order to get a brief overview about the chacacteristics of each store, some basic information about the building infrastructure and the technological system are described in the following section.

The system technology in store A was technically updated in 2015. The refrigeration-system is based on the refrigerant CO_2 and corresponds accordingly the state-of-the-art. However, not all freezers are connected to the LC (low-cooling) or DF (deep-freeze) compound refrigeration-system. In total, six units are not connected to the compound refrigeration system. One of these units (DC) can be locked by doors and two of the corresponding five LC-units can also be locked. The non-lockable freezers have a significantly higher power consumption compared to the lockable freezers. In terms of CO_2-emissions, this underlines that there might be additional direct emissions apart from the indirect emissions listed in Table 2 (~208,000 $kgCO_2$). The store is heated mainly through heat recovery of the refrigeration-system. The heat is transferred via heat exchangers to the ventilation-system and then to the market. In addition, a gas condensing boiler has been installed for an additional support. The lighting-system of the store is completely based on LED-technology. Furthermore, a photovoltaic-system is installed in this store, both influencing the total electricity consumption and peak loads.

Store B has been renovated in 2017. In this regard, LED-lighting has been installed in the whole market. The store is heated with a similar system that is used in store A. The stores' refrigeration units are connected to the compound refrigeration-system for LC and DF based on CO_2 as refrigerant. Consequently, the indirect emissions (~319,000 $kgCO_2$) correspont approximately the total emissions of the store. Most of the refrigeration units are also door-lockable systems. However, the refrigeration section for dairy products cannot be closed by doors. Although these refrigeration units are fitted with roller blinds for a temporary covering outside the opening hours, the refrigeration requirements are still much higher than in closed systems. In addition, the effectiveness of the covering is questionable, as it may affect the air curtain designed to prevent "cold losses". This could lead to even higher energy consumptions. Even if this effect does not occur, such a cover does not necessarily lead to a lower energy demand [26].

Store C was built in 2009 according to the requirements of the *EnEV* (German energy saving regulation) and has not yet been renovated. However, this store will be refurbished in 2020. The store has the largest sales area and customer numbers (Table 2). Although the system technology is from 2009, the refrigeration-system already uses CO_2 as refrigerant. In contrast to the other two stores store C is heated via an additional heating system consisting of a gas condensing boiler. Regarding the CO_2 emissions, this has to be taken into consideration. In total, this results in additional 70,000 $kgCO_2$ due to a natural gas consumption of 350,000 kWh/a[‡]. The heating of the store is not only taken over by the waste heat of the compound refrigeration-system. The sales area is heated by the ventilation-system and a ceiling air heater. Further areas of the store are heated by wall radiators. The lighting in the store has also been updated to LED-technology. The same applies to the exterior lighting. Several ovens, stoves and refrigerated counters in a kind of bistro in the middle of the sales room have been identified as other large consumers.

Figure 3 shows the total electricity consumption of each stores' reference week based on the short-term measurements. Furthermore, the electricity consumption and percentage share of the measured sub-sections are displayed in the diagrams. The sub-sections energy consumption is evaluated through the aggregation of the measurement data from Monday to Sunday in the reference week.

[‡] Evaluated with a CO_2 emission factor of natural gas in Germany (2016): 0,201 kg/kWh [27].

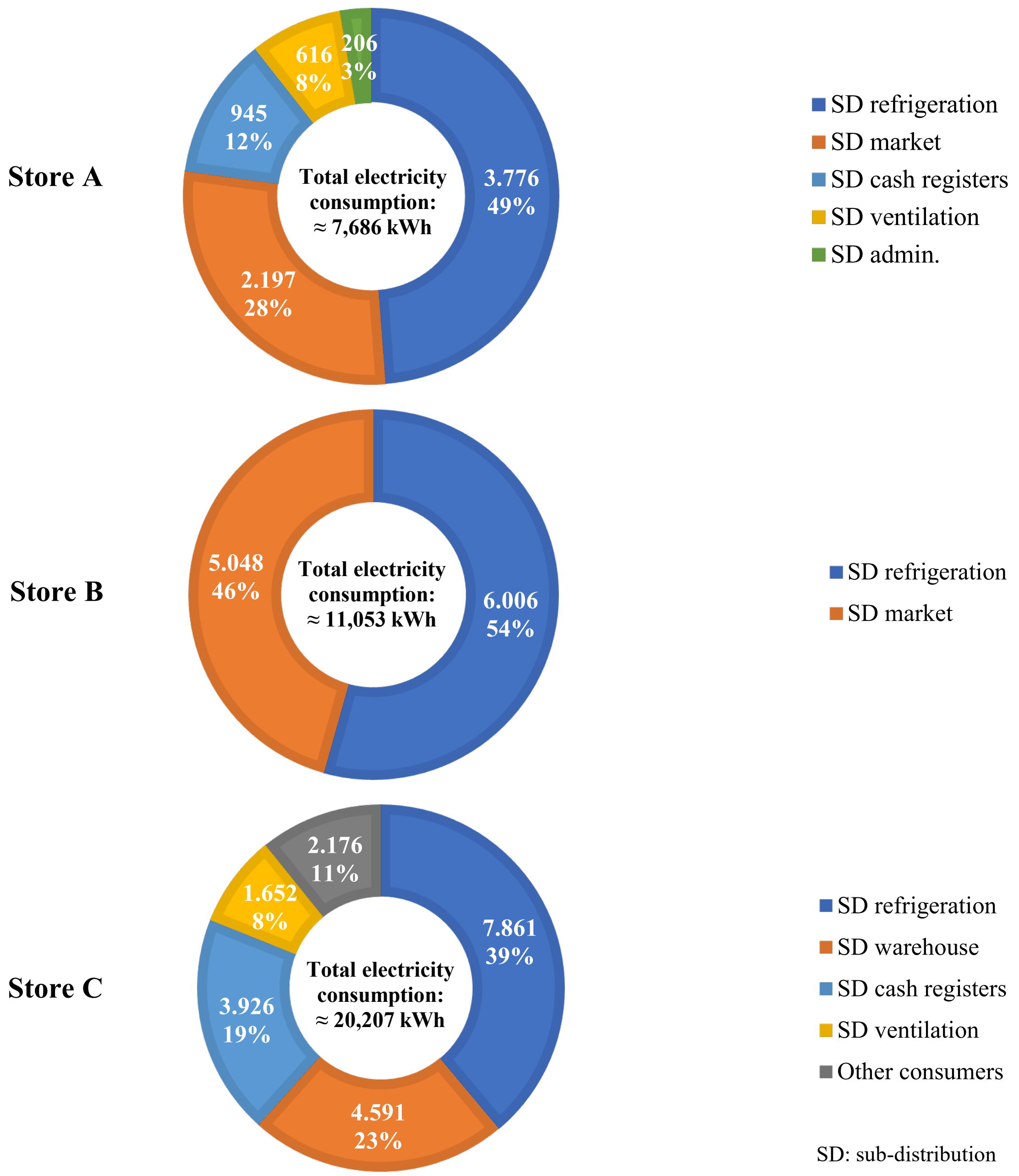

Figure 3. Electricity consumption and percentage share of the measured sub-sections on the total electricity consumption in each stores' reference week

In the short-term measurement of store A, the sub-distributions refrigeration, market, cash registers, ventilation and administration could be inlcuded. While the sub-sections refrigeration, cash registers and ventilation can be assigned to a consumer group, "SD market" contains a mix of various consumers in the sales room such as the lighting-system or dezentralised refrigeration units. The electrical sub-distribution of store B was only separated into the sub-sections "SD refrigeration" and "SD market". Due to this, it can be assumend that the sub-section "market" includes a broad mix of consumers (cash registers, lighting-system, ventilation). However, the sub-distribution in store C could be analysed as detailed as in store A (Figure 3). In addition to the the sub-sections in store A, the electricity consumption of "SD warehouse" was measured. Due to the size of this store, not every sub-section could be connected to the mobile measurement-system. In this case, the sub-sections with the highest currents are measured parallel to the total electricity consumption of the store. The difference between the total electricity consumption and the sum of the five sub-sections is outlined as “Other consumers” in Figure 3.

In total, the energetic analysis of the grocery stores has shown that all three markets are in a comparatively good energetic condition. The common energy efficiency measurements such as switching to an LED lighting-system or the use of a compound refrigeration-systems based on carbon dioxide as refrigerant including a heat recovery-system is already implemented in the stores (except store C, which will be renovated in 2020). From an environmental perspective, using the refrigerant CO_2 avoids direct emissions and lowers the environmental pollution of each store. However, the energetic data provided by the mobile measurement-system allows a deeper analysis of peak loads in load profiles as well as the identification of specific benchmarking values. These topics are described in the following sections.

Peak load analysis

Dealing with peak loads is important in the retail sector as well as in other branches, since the maximum peak load is charged by the demand rate in the utilitys’ energy bill. It’s not decisive at what time of the year the peak load occurs, but the amount of the peak load (in kW) directly affects the total energy costs since it’s multiplied by the demand rate (~ 80-100 €/kW) [28]. The operating hours of all three markets are above 2.500 h/a, which indicates a high utilisation. Utilities calculate a higher demand rate in €/kW/a and a lower energy price (€/kWh) at operating hours above 2.500 h/a. In terms of energy savings, capping or shifting peak loads has a significant financial impact, even if the total energy consumption remains the same.

The consumption structure of store B and C (without photovoltaic-system) are similar to each other. There are peak loads both in the morning and in the afternoon. The analysis of the energetic data of 2018 has shown that peak loads occur on the 26th July at noon in store B and C. In comparison to these two markets, store A (with photovoltaic-system) shows a different characteristic regarding peak loads. The maximum peak load over the whole year occurs on 16th February in the morning hours. Due to this circumstance, it can be assumed that the installed photovoltaic-system directly affects the occurrence and height of peak loads. The photovoltaic-system partly covers the electricity consumption of store A, resulting in a direct effect on the electricity meter which measures the balance sum of the consumptions and production profile. This explains the occurrence of peak loads in store A in the morning, as there is no solar radiation at this time.

The short-term measurement-data allowed a deeper analysis of the peak loads in each sub-section. The analysis of the measurement data of store A has shown that the highest peak loads occur in the sub-distributions market (25 kW) and cash registers (15 kW) between 05:00 and 06:00 am although the stores operating time starts at 07:00 am. The load profile of the sub-section refrigeration also shows several peaks in the morning, but these are not as high as in the other sub-sections. As a result, it can be assumed that neither the refrigeration-system nor the customer numbers are responsible for the peak loads in store A. The peak load analysis in the sub-sections of store B and C shows similar results. As mentioned in the analysis of the consumption data above, the highest peak loads in the measurement data also occur during noon. The load profiles in these stores underlined that only the sub-section refrigeration shows peaks at noon. Due to this, it can be assumend that most peak loads can be traced to the refrigeration system in stores without a photovoltaic system. This is underlined by the fact that the energy consumption of the whole store, but especially the sub-section refrigeration is depending on the outdoor temperature. Increased outdoor temperatures, which often occur at noon, result in an increasing energy consumption of the refrigeration-system.

The detailed peak load analysis also represents a basis for the identification of flexbible loads and the potential to shift or ruduce loads in specific time periods. In case of store A, the peak loads in the morning probably occur due to the simultaneous switching on of all consumers in the morning (esp. sub-sections cash registers and market). The fact that the peak arises outside the operating time of the store result in the potential for a time period to shift peak loads into the time range of the stores' opening hours. The identified peak loads in store B and C occur during the operating time of the market. Shifting or reducing these peaks require a load management-system which considers both current and historical operating data. Thus, preventive measures can be taken to avoid peak loads.

Benchmarking analysis

In the following, an energetic comparison of the three grocery stores is carried out based on a benchmarking analysis. All EnPIs are based on energetic data determined in on-site investigations of the three stores. As described in section *Method*, sales area (m²) and "customer numbers" () are considered as operating data for this benchmarking analysis.

The following figure shows the comparison of each stores' EnPI based on "sales area" both for the total energy consumption (blue bars) and the sub-section "refrigeration" (orange bars) (Figure 4).

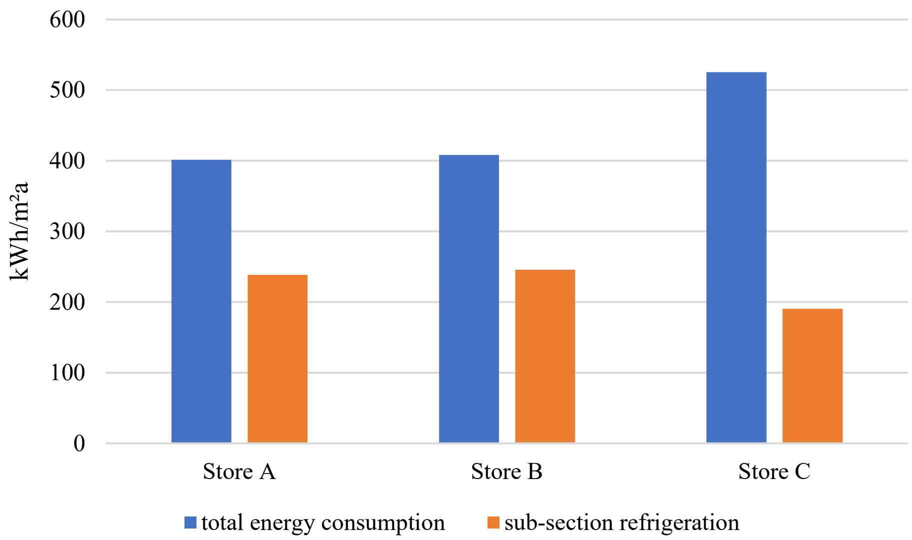

Figure 4. EnPI based on "sales area" both for total energy consumption (blue bars) and sub-section "refrigeration" (orange bars)

The figure shows that store C has the highest energy demand per m^2, but at once the lowest cooling demand per m² sales area. This can be explained by several circumstances. First of all, not only electricity but also thermal energy is considered as total energy consumption in this analysis. Especially the natural gas consumption in store C has a huge impact on the EnPIs due to a thermal energy consumption of 350,000 kWh/a. In contrast, store A and B cover most of their thermal energy demand by the heat recovery-system, which is linked to the refrigeration system. Due to this circumstance, the increased EnPIs for the sub-section refrigeration could also be affected by the heat recovery-systems in these stores. If the EnPI of each store is based on the total electricity consumption, all three stores show almost equal benchmarking values (~ 400 kWh/m²a) despite store C is not renovated. However, this can be explained due to the higher energy demand for refrigeration in store A and B. If the energy consumption of the sub-section refrigeration is substracted from the total electricity consumption, the lower technological standard in store C becomes apparent. There's a gap of around 60 kWh/m²a between store C and the renovated stores A and B. Furthermore, Figure 4 shows that the EnPIs for store A and B are almost identical although store A has installed a photovoltaic-system. This might be the case due to a couple of refrigeration units in store A that are not connected to the compound refrigeration-system. As there are no decentralised refrigeration units in store B, this coud explain the equal EnPIs of the two stores.

In conclution, store C has the highest EnPI based on sales area due to it's unrenovated state, while store A and B show nearly identical EnPIs about 120 kWh/m²a lower than store C. In this case, the mobile measurements of the sub-sections enabled a deeper analyis and comparison of the energetic conditions in the three stores.

Unlike the sales area, which can be classified as a static operating value, "customer numbers" is characterised as a dynamic value due to its ability to change depending on a time period. For the following benchmarking analysis, customer numbers of 2018 have been consulted. Figure 5 shows the developed EnPIs based on customer numbers for all three stores.

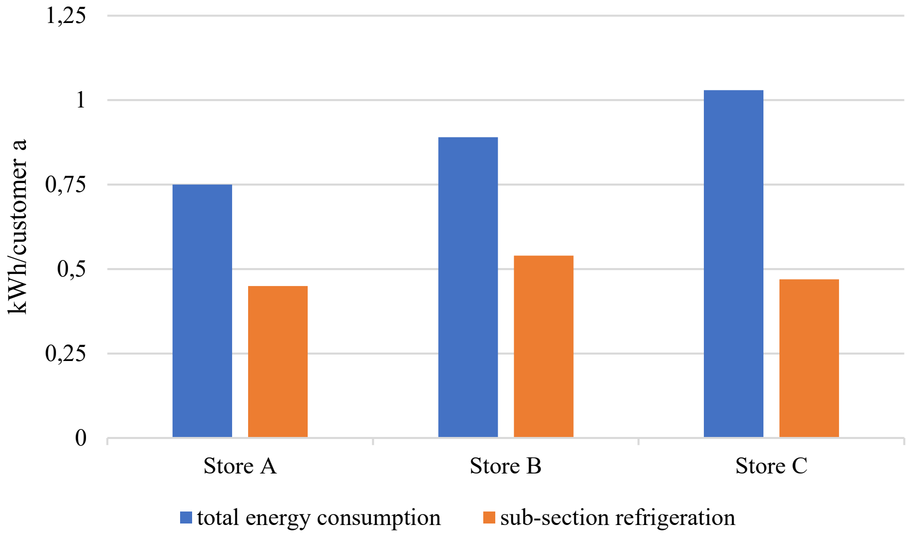

Figure 5. EnPI based on "customer numbers" both for total energy consumption (blue bars) and sub-section "refrigeration" (orange bars)

As it can be seen in the figure above, store A has the lowest EnPI regarding the total energy consumption (0.75 kWh/customer a) followed by store B (0.89 kWh/customer a) and store C (1.03 kWh/customer a). Despite the similar degree of refurbishment of in store A and B, the EnPI of store A is way lower due to the installed photovoltaic-system. Considering that sales area has a significant impact on the energy consumption, stores with a higher "customer per m²-ratio" require less lighting and thermal energy per customer. As store A shows the highest ratio followed by store B (-10 % compared to A) and store C (-20 % compared to A), the EnPIs are in line with this dependence.

By breaking down these values to the sub-section refrigeration, Figure 5 illustrates that the EnPIs are more levelled. One reason for this effect could be the fact that the energy consumption data of the refrigeration-systems are way more adjusted than the stores' total energy consumption. Whereas the sub-section "refrigeration-system" just include compressors and pumps, the total energy consumption of the market can be affected by various consumers which are dependend on the sales area. However, the minimal differences between the EnPIs could underline the thesis that the exclusive energy consumption of the refrigeration-system does not correlate coincidently with customer numbers and sales area. This would mean that the sales are has no effect on the EnPI based on custumer numbers.

DISCUSSION

This section discusses the results of the energetc analysis and compares it to literature values. Furthermore, the approach for both data collection process and data evaluation including the energetic comparison of the grocery stores is critically reflected and questioned.

As shown in Figure 3, the largest consumer-group in all markets was the measured sub-distribution (SD) "refrigeration". It accounts for 39-54 % of the total consumption of each market. These values correspond well with the average literature value (46 %) provided by *ehi Retail Institute (2017)* [19]. Under all sub-sections, "refrigeration" was the only one that was classified as "seasonal fluctuative" due to the correlation of the energy consumption with the outdoor temperature. Furthermore, the ventilation-systems measured in store A and C both have reached a share of 8 % of the total consumption in the respective reference week. This figure corresponds exactly the literature values from *ehi Retail Institute (2017)* [19]. However, the literature review did not provide reference values for the other sub-sections such as market, warehouse or cash registers. Nevertheless, the comparatively huge electricity consumption of the sub-section cash registers measured in store A (12 % share on total consumption) and C (19 % share on total consumption) was quite unexpected.

The calculated energy performance indicators (EnPIs) for the sales area (m²) illustrated in Figure 4 are corresponding to literature values listed in Table 1. The EnPIs of store A and B are roughly corresponing to the average value 401 kWh/m²a from *ehi Retail Institute (2017)* [19]. This underlines that these retail stores are averaged according to the energy consumption, whereas store C (515 kWh/m²a, not yet renovated) is well above the average literature value. The literature review on EnPIs for the retail sector (esp. food-sector) assume that the energy consumption is only dependent on a single factor such as sales area or customer numbers. The benchmarking analysis in this study has shown that EnPIs are often affected by several operating data, as the "customer per m²-ratio" underlined. As a result, EnPIs based on more than one factor should be implemented (e.g. sales area and customer numbers). However, another more detailed approach for the development of a benchmarking system is described in DIN EN ISO 50006 (*Measuring energy performance using energy baselines (EnB) and energy performance indicators (EnPI)*), wherein the formation of energy baselines and enerprise-relevant EnPIs are proposed. With the help of regression analyses, a normalisation of the energy consumption is implemented in this extended approach [29]. With the help of regression analyses, a way more analytic benchmarking approach could also be applied using a mobile measurement-system, since the approach described in [29] is not based on short-term measurements.

In this study, the methodogical approach (*Hilger, Schneiders (2020)* [12]) using a mobile measurement-system as a tool to get transparency into the energy flows of an enterprise was extended by a benchmarking analyis and energetic comparison of multiple stores. Although the measurement-system could be implemented in each of the three stores, it was not possible to identify the sub-sections in store B as detailed as in store A and C due to the structure of the low voltage main distribution. Therefore, the benchmarking analysis was limited to the data available in each of the three stores. The short-term measurements carried out in the stores may not be representative for analyses based on longer periods of time, since seasonal fluctuations are not considered. However, the systematic and structured use of a mobile measurement-system provides an efficient approach to quantify energy consumption on a sub-sectional level. This results in additional benefits compared to energetic analyses without mobile measurement-systems. Further, the upscaling of short-term measurements on a longer time period (e.g. a year) has been assessed intensively in the reasearch project *"Teilenergiekennwerte"* [30]. For the ongoing measurement-campaigns in enterprises, the results of this project shall be implemented in the approach presented in this study.

CONCLUSION

This research provides new insights that contribute to the development of an approach using a mobile measurement system as a tool for the energetic analysis of enterprises. This is achieved through the implementation of a measurement-campaign in three grocery stores focusing on the benefits and added value using the energetic data from the measurement-system for the energetic comparison and benchmarking analysis. The research has shown that the energetic data from the measurement-system enabled the determination of energy performance indicators (EnPIs) based on operating data such as sales area and customer numbers. In particular, the mobile measurement-system used in this study measured up to six sub-sections in the low voltage main distribution of each store in parallel. Thus, measurements on the sub-sectional level provided a lot of information about the consumption structure and the energetic behavior of individual consumer groups. This allowed the determination of the percentage share of each measured sub-section on the total electricity consumption of a store in a reference week as well as its comparison to related literature. Among the findings of the benchmarking analysis, the reasearch has shown that some EnPIs developed in this study correspond to the values from related studies. However, it became clear that the development of enterprise-specific EnPIs based on more than one operating value is important for future measurement campaigns.

Regarding the energetic analysis of the grocery stores, this research has found that the energetic condition of the stores corresponds to the status quo desrcibed in literature. On-site investigations in the grocery stores have shown that common energy efficiency measurements such as switching to LED-lighting or using compound refrigeration-systems based on the refrigerant CO_2 are already implemented. From an environmental perspective, using the refrigerant CO_2 avoids direct emissions and lowers the environmental pollution of each store.

Finally, this research has identified a methogical approach creating energy performance indicators using a mobile measurement-system. Future research is required on the specification of EnPIs and the consideration of seasonal flucuations in short-term measurements. Furthermore, benchmarking across industries enables a cross-sectoral energetic comparison. Future research in this area could lead to new insights due to the use of a mobile measurement-system on a sub-sectional level.

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