Energy metering and management practices of manufacturing companies: A systematic literature review

by

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Abstract

While metering and management of energy costs plays a significant role in energy intensive companies, the application of energy costs management in non-energy intensive companies is rarely addressed in the literature. Based on a systematic literature review, we investigate energy management practices in energy intensive vs. non-energy intensive companies. We also distinguish between differences in practices of small and medium enterprises (SME) vs. large companies. Specifically, we address how companies measure energy usage and costs, and use the data for energy management purposes, mainly for analyzing energy related investments. The literature review covers 19 journals in the fields of business, accounting, energy, and engineering, using keywords such as “energy management,” “energy metering,” or “energy measuring.” The final sample includes 45 papers for the analysis. The findings suggest that most literature concerns energy intensive and large companies.

The most important findings are based on the few studies that cover non-energy intensive companies. These use imprecise methods for measuring and allocating energy costs. The majority of companies do not allocate energy costs at all, a minority of companies uses sub-metering to track energy consumption within the company, and others allocate costs roughly, such as per square meter or per employee. There are almost no studies that provide a more nuanced description of measuring and allocating energy costs, for example by investigating specific cost allocation bases, the accuracy of cost allocations, and differentiating between first stage and second stage allocation. Still, the overall impression is that many non-energy intensive companies may lack much of the information necessary for energy management, such as information needed for improving energy efficiency, evaluating the financial benefits and costs of energy efficiency improvement investments, and holding managers accountable for energy efficiency.

Keywords

Energy management, energy cost, energy intensity, manufacturing, energy metering

Introduction

Climate change and global energy consumption are forcing policy-makers to focus more on sustainability and energy efficiency. The goal of the European Union is to reduce greenhouse gas emissions by 20% until 2020, compared to the year 1990. Furthermore, the share of energy consumption met by renewable energy sources should reach a goal of 20% and energy efficiency should be increased by 20% by 2020 (European Commission, 2011). The industrial sector, as one of the main consumers of energy as well as one of the largest emitters of CO2, plays a crucial role in reaching that goal. The energy consumption of the companies in the industrial sector in 2014 was 26% of the total energy consumption in EU (Eurostat, 2016). Moreover, companies are facing continuously rising energy prices and therefore internal incentives also exist for companies to reduce their energy consumption and increase their energy efficiency in order to reduce their energy costs.

Even though interest in the area of energy management is increasing, so far there is no consistent definition of the term “energy management” in the existing literature. O’Callaghan and Probert (1997) define energy management as applying “to resources as well as to the supply, conversion and utilization of energy. Essentially it involves monitoring, measuring, recording, analyzing, critically examining, controlling and redirecting energy and material flows through systems so that least power is expended to achieve worthwhile aims”. Another definition is given recently by Schulze et al. (2015) based on their extensive literature review. They define energy management as a combination of “systematic activities, procedures and routines within an industrial company including the elements strategy/planning, implementation/operation, controlling, organization and culture and involving both production and support processes, which aim to continuously reduce the company's energy consumption and its related energy costs”. In their paper they also provide an extensive list of selected definitions of energy management (Schulze et al., 2015).

Information on the energy usage within a company can be expected to positively contribute to energy-related investment decision making by improving the information basis. Such information are often addressed in the literature on energy intensive or large companies, where metering and management of energy costs plays a significant role. On the other hand, practices in non-energy intensive or small and medium enterprises (SMEs) are not that well researched, even though the potential for energy savings in those companies could be great. Because of that we focus our paper on characteristics of companies in order to compare differences in practices of metering and management of energy costs. Many of the existing papers focus on the wider topic of energy management. Yet, to the best of our knowledge, no literature review so far describes energy measurement and management practices in manufacturing companies with emphasis on empirical data on a company level. Therefore, this paper aims to systematically review a rather broad range of studies and contribute to a better understanding of how companies measure and allocate energy costs and how this depends on energy intensity and size of the company.

Manufacturing industries with a high share of energy costs as a proportion of total costs, such as iron and steel, cement, pulp and paper and chemicals industry, are known as energy intensive industries (U.S. Energy Information Association (EIA), 2016). On the other hand, energy costs in the non-energy intensive industries represent only a small percentage of total costs. Thollander and Ottosson (2010a) highlight the fact that non-energy-intensive companies have energy costs in relation to the added value of only a few percent, while energy-intensive industries like foundries are facing costs of 5-15%, and energy-intensive process industries like pulp and paper mills are facing costs well beyond 20% (SFA, 2004, SEA, 2000, as cited in (Thollander & Ottosson, 2010a)). Many non-energy intensive companies use coarse methods for measuring and allocating energy costs, and so their energy cost information is likely to be inaccurate. As a result, they may lack much of the information necessary for energy management, such as information needed for improving energy efficiency, evaluating the financial benefits and costs of energy efficiency improvement investments, and holding managers accountable for energy efficiency.

Additionally, small and medium enterprises (SMEs) that are either energy intensive or non-energy intensive companies in many cases pay less attention to energy efficiency. The reasons for this are that they often do not have a dedicated person to take care of energy issues or because of a rather small energy saving potential at a single company (Shipley & Elliot, 2001). It is often also difficult to trace which activities use most energy because of a large number of processes in a company (Shipley & Elliot, 2001). According to the European Commission, small and medium sized enterprises (SMEs) are companies with less than 250 employees and with an annual turnover of less than 50 million euros (European Commission, 2012). Yet, as reported by European Commission in 2009, SMEs account for about 99% of total enterprises, approximately 58% of total value added, and create nearly 3.25 million jobs in the EU.

Companies where energy costs make only a small part of the total cost of production usually face several problems regarding energy costs (Muller et al., 2007). In these companies energy often has a lower priority in daily management and they often lack resources for energy monitoring and implementing energy efficiency projects. As a consequence, there is usually a low level of metering energy consumption and this is considered to be a barrier when implementing an energy management program.

As Zolkowski and Nichols (2016) point out, many companies still perceive energy as part of overhead costs that cannot be managed, so the energy is often left as the largest unmanaged potential. Also in the companies where energy costs represent only a small fraction of total costs, there could be other drivers for managing them, such as environmental performance. The problem is similar in SMEs, which was detected by Gruber and Brand (1991). They argue that SMEs do not have enough information about their energy costs and tend to underestimate the monetary potential of energy efficiency improvements in their company, and also mention the lack of sub-metering and energy management as one of the main barriers to energy efficiency in small and medium companies.

Energy monitoring within companies is also related to motivational implications, as departments are incentivized to improve their energy consumption if they can actually be held accountable for the result. If this was not the case, split incentive problems may arise (Sorrell et al., 2011). As Thollander and Ottosson (2010a) also point out, the dedication of department managers to reduce energy consumption will be lower if energy costs are not allocated based on actual energy use, which is also known in the literature as split incentives problem.

The literature review was guided by the following four initial research questions:
Research Question 1: How are companies measuring energy costs and what are their energy management practices?
Research Question 2: What are the other common characteristics of these companies?
Research Question 3: How are companies allocating energy costs?
Research Question 4: What are energy strategies of companies in selected papers?

We conducted a systematic literature search that yielded 45 empirical papers in 19 journals in the field of management accounting and energy. We started the search process by scanning journals for topic-related keywords, followed by an extensive backward and forward citation analysis. This led to a final count of 45 relevant papers. We constructed an overview table to distinguish between specific characteristics of companies and methods observed in selected papers. This new perspective helped us in showing similarities and pointing out gaps in the literature.

Our review results in four main findings. First, 73.3% of the relevant papers mainly focus on metering and energy management practices in energy intensive companies, while only 17.8% of the papers focus on non-energy intensive companies. Second, it is shown that non-energy intensive companies monitor and measure energy usage to a small extent, and even when the energy audits are made, they rarely lead to investments in energy conservations, because it is considered to be more profitable to do nothing. Third, 13.3% of the papers reviewed address allocation of energy costs to departments, and only one paper addresses second stage allocation, i.e. the allocation of energy costs from departments to products or cost centers. Fourth, far less non-energy intensive companies have clearly formulated and long term energy strategies then energy intensive companies.

The remainder of the paper is organized as follows: In the next section, we describe the research method applied to the four research questions. We then present our findings. In the last section, we discuss our findings and suggest implications for further research.

Research method

To investigate energy metering and management practices in manufacturing companies, we conducted a systematic literature review according to guidelines provided by Tranfield et al. (2003). We also focus on differences of characteristics of companies, for example including data that describes whether companies are energy intensive or non-energy intensive, or small and medium sized or large. This new perspective helped us in showing similarities between the types of companies, but also in pointing out gaps in the literature.

In the first step, we defined our research objective: to provide a comprehensive overview of common energy measurement and management practices in manufacturing companies with emphasis on empirical data on a company level, in order to advance the understanding of this topic. To attain this goal, we highlighted four research questions: 1. How are companies measuring energy costs and what are their energy management practices? 2. What are the other common characteristics of these companies? 3. How are companies allocating energy costs? 4. What are energy strategies of companies in selected papers?

In the second step, we focused only on research articles and literature reviews published in peer-reviewed academic journals, and disregarded other publications, such as conference papers, books and working papers, as they are not subject to such a rigorous process before publishing. The selected papers also had to be written in English, available online as a full text and the publication year had to be after 1995. This year was selected because our preliminary search showed that the number of articles published before is small, but also because of our focus on contemporary metering practices. To ensure complete coverage we used two databases of academic publications, Scopus and Google Scholar. First we used Scopus database by Elsevier, combining search terms and Boolean operators in order to narrow the results down as accurately as possible. Search terms included “energy measur*”, “energy management” and “energy metering” in the title, and term “industry” in the title, abstract or keywords of a paper.[1] The asterisk (*) is used to include all variants of the word, such as measurement, measuring or measure.

Initial search yielded 492 publications, of which 445 were research articles and 47 were literature reviews. Analysis of these articles, performed by reading journal names, article titles, keywords, abstracts and introductions, revealed that most of these articles identified by our search would not be useful for writing this review. Many of them focused on industries other than manufacturing, or were theoretical studies, or the focus was on statistical analysis on the level of industry, and without including company-specific data. After reviewing results of this search, we identified 20 relevant papers. Furthermore, we conducted a backward and forward citation analysis based on 20 relevant studies from the initial search. We analyzed the references (backward citation analysis) and used Google Scholar to identify more recent publications citing a paper (forward citation analysis). After including new papers found by using backward and forward analysis, we had 43 papers. The initial search was not otherwise limited because of the expectation that the search query would return results in diverse research areas. This expectation proved to be correct, with several results in the fields of Business, Management and accounting, Energy, Engineering and Environmental science.

Moreover, we found that some journals reoccur more than three results in the first step of the search. To ensure complete coverage, we did a further search only on those journals where we found three or more articles: *Applied Energy*, *Energy*, *Journal of Cleaner Production*, and *Strategic Planning for Energy and the Environment*. This time we used the same search terms, but now in the “title, abstract and keywords” of papers, to get more detailed results.[2] Also, we conducted another detailed search, with the name of the author

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[1] ((TITLE (energy measur*) OR TITLE (energy management) OR TITLE (energy metering) AND TITLE-ABS-KEY (industry)) AND DOCTYPE (ar OR re) AND PUBYEAR > 1994) AND (LIMIT-TO (LANGUAGE , "English"))

[2] (ISSN(0959-6526) AND (TITLE-ABS-KEY(energy measur*) OR TITLE-ABS-KEY(energy management) OR TITLE-ABS-KEY(energy metering) AND TITLE-ABS-KEY(industry))) AND DOCTYPE(ar OR re) AND PUBYEAR > 1994 AND (LIMIT-

as a keyword in a search term, for authors whose name reoccurs two or more times in the initial search: Thollander, Johansson, Ottosson and Söderström.[3]

A full textual analysis was conducted on the papers which matched our criteria, which provided information regarding our research questions and requirements. To get the information that would answer our research questions, we focused on papers about energy management with empirical data on a company level. We then searched for information about energy measurements, allocations of energy costs, energy strategy and criteria for investments. Therefore papers with statistical analysis, theoretical or technical work which did not include any kind of empirical data or field work, in terms of case studies, questionnaires or surveys were excluded. Also, there was a clear focus on company level data, so papers which conducted analysis on a sector or industry level were also excluded.

This process resulted in obtaining 45 relevant papers distributed over 19 journals (Table 1). A table containing more detailed information of these 45 papers is attached in the Appendix (Table 2). In that overview table we include detailed information that follows the logic of our research questions. We divide table into columns on characteristics of companies, details about energy measurement practices, allocation of energy costs and available information on energy-related decisions. Findings are discussed in more detail in following chapters.

Journal	
Applied Energy	7
Applied Thermal Engineering	1
Chemical Engineering and Processing: Process Intensification	1
Energy	5
Energy Conversion and Management	2
Energy Efficiency	2
Energy Engineering	2
Energy Policy	2
Energy Procedia	2
International Energy Journal	1
International Journal of Energy Research	1
International Journal of Scientific & Technology Research	1
Journal of Cleaner Production	10
Journal of Environmental Economics and Management	1
Management Accounting Research	1
Procedia CIRP	1
Production and Operations Management	1
Strategic Planning for Energy and the Environment	3
Sustainable Energy Technologies and Assessments	1
Sum	**45**

Table 1. Journal yielded by the final search of 45 relevant publications

TO(LANGUAGE,"English"))

[3] (AUTH (Thollander) AND (TITLE-ABS-KEY(energy measur*) OR TITLE-ABS-KEY(energy management) OR TITLE-ABS-KEY(energy metering) AND TITLE-ABS-KEY(industry))) AND DOCTYPE(ar OR re) AND PUBYEAR > 1994 AND (LIMIT-TO(LANGUAGE,"English"))

Results

Descriptive analysis

The results are strongly dominated by three journals: *Journal of Cleaner Production*, *Applied Energy*, and *Energy*. These three journals published almost half (49%) of all observed studies.

Figure 1 illustrates the publication years of the relevant literature that was found. Most of the papers were published after 2012, which clearly shows the increasing importance of this topic to researchers and industry.

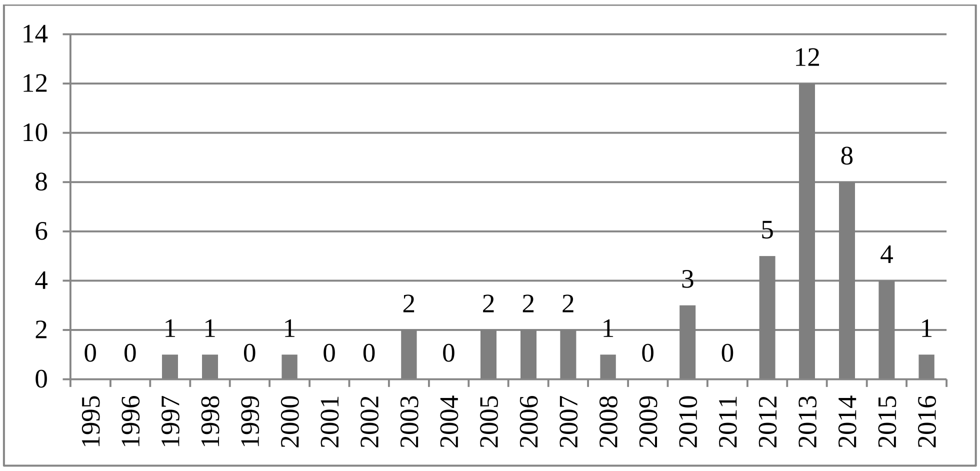

Figure 1. Distribution of the 45 relevant studies by the year of publication

Figure 2 illustrates the distribution regarding the company size. We used European Commission's definition (mentioned in the introduction) when there was enough information in a paper to do so, otherwise we assumed the categories mentioned in the paper itself. In their literature review from 2015, Schulze et al. (2015) discovered that empirical papers in the field of energy management focus more on large companies then on SMEs. Our results confirm this finding, as there are 24 papers with the focus on large companies and only 5 papers with focus on SMEs. In 13 papers both SMEs and large companies were observed, and in 3 papers the size of the company was not specified.

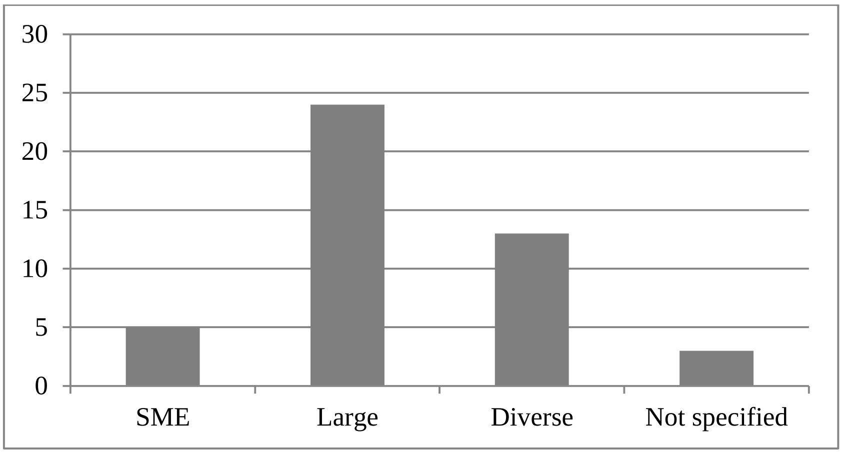

Figure 2. Distribution of the studies by the company size

We define case study as in-depth investigation of practices and procedures within one or a small number of companies (up to three companies). Similarly, multiple case studies focus on such investigations in a larger number of companies, often comparing findings to derive better insights. When there was enough information in the paper we used definitions mentioned above, and in other cases we assumed research method mentioned in a paper itself. The most commonly used research method was case studies, used in 27 papers (60%). Other methods included multiple case studies, interviews, surveys and questionnaires. This is illustrated in Figure 3.

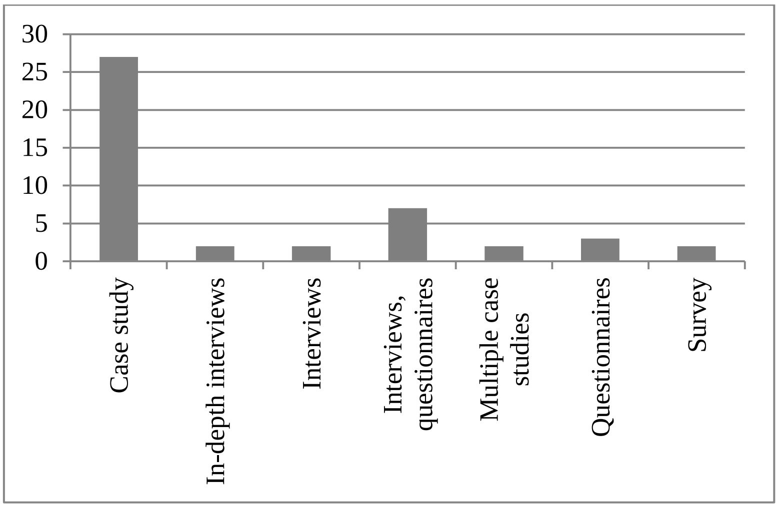

Figure 3. Research method

As already mentioned in the Introduction, we can differentiate companies based on their energy intensity on energy intensive and non-energy intensive companies. In most cases we assumed the energy intensity level of the company as it was mentioned in the paper. Where that information was not given, we labelled it as energy intensive or not based on the industry the company was in and the categorization of industries according to the US Energy information association (2016). Thirty-three (73.3%) of the papers in our sample had energy intensive companies in main focus, and only 8 (17.8%) focused on non-energy intensive companies. Other two categories include papers with both energy intensive and non-energy intensive companies, and papers where such distinction is not known. This is illustrated in Figure 4.

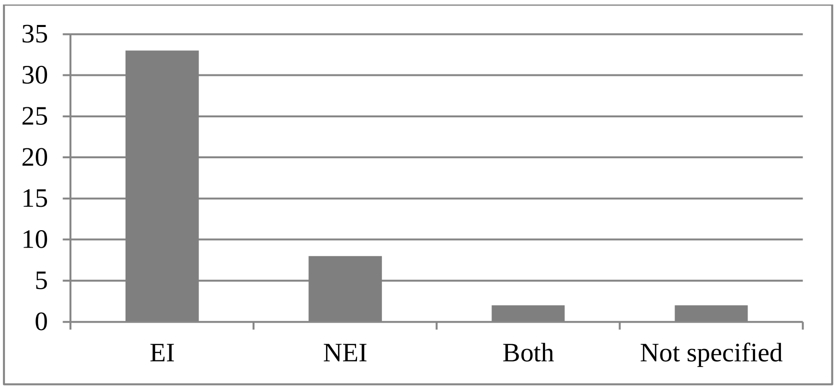

Figure 4. Energy intensity levels

In Figure 5, the detailed distribution on industries is illustrated.

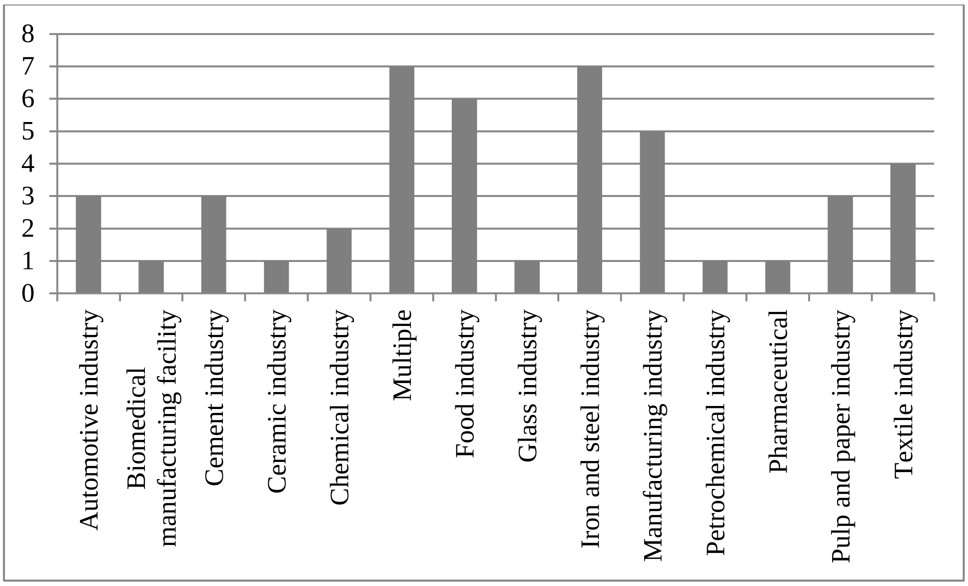

Figure 5. Industry sector focus

Energy metering

In this section we first define and present methods for monitoring and metering energy costs in companies, with focus on Best Available Techniques which provide a good overview of the methods. We then present findings on energy metering practices from our systematic literature review.

Best Available Techniques (BAT) reference documents issued by Joint Research Centre of European Commission (BREF on Energy Efficiency, 2009) describe several techniques that can be used to measure, calculate and monitor energy properties of activities in companies. Accuracy of measurements of energy costs can have a large impact on decision-making in a company, so it is necessary to base those decisions on accurate and trusted data of real energy consumption instead on estimations. In cases where energy consumption of an activity is relatively small comparing to the whole system, estimations and calculations could still be used (European Comission, 2009). Estimations and calculations are one of the possible energy measuring techniques, besides sub-metering and ultrasonic metering, which are more advanced and more accurate techniques. Calculations are often based on an easily measured parameter whereas other parameters are given by the equipment manufacturer (one example of that could be an industrial oven with number of hours in use as an easily measured parameter, and other information used to calculate energy consumption provided by the manufacturer). Similarly, estimations are based on specifications given by the manufacturer. According to the European Commission, even though these methods are widely used, they can also lead to expensive errors due to wrong calculations or estimates.

Another method used by many companies is sub-metering with either traditional or advanced meters. Traditional utility meters are usually manually read and measure amount of energy used by a system. They also serve as a base for generation of energy bills. Another type of sub-metering is with advanced metering systems which uses more complex meters (for water, fuel, electricity etc.). They usually measure energy consumption and collect energy data in regular time intervals. Advanced meters are more precise, but also more expensive method of gathering data, so they are often used in companies with multiple activities and energy sources used in production. Lastly, ultrasonic metering can be used in measuring liquids, but these kinds of meters can be rather expensive, so they are often introduced only at new installations or during significant upgrades (European Comission, 2009).

To be able to gather detailed and reliable information on energy consumption, it is important to collect data on the type and amount of energy used, but also the time interval in which the data was collected. Moreover, the level of accuracy increases with the level of detail of the collected data. For example, it would be possible to include measurements that include exact energy transfers from one system to another, like residual heat. Another possibility for increasing accuracy is automatization of meters and collection of energy usage data in shorter time intervals.

In an analysis of Swedish iron and steel industry, Brunke et al. (2014) found that when it comes to the type of energy measured, all of the observed companies meter electricity, and only about 70% meter fuel, steam and hot water (Brunke et al., 2014). SMEs usually purchase energy from the grid, while self-generation with CHP or other power plants are more widespread within larger companies (Aflaki et al., 2013) and energy-intensive companies (Johansson & Söderström, 2011; Kong et al., 2013; Li et al., 2010; Sathitbun-anan & Fungtammasan, 2015).

As Best Available Techniques of European Commission summarize, there are several data sets that should be recorded for every energy source. For electrically powered device the data on rated power, efficiency, load factor and working hours per year should be gathered. For equipment consuming fuel the data on type of fuel supplied in a specific time period, kind of thermal carrier entering the boiler: flowrate, temperature, pressure; condensate: percentage of recovery, temperature and pressure; boiler body: manufacturer, model, installation year, thermal power, rated efficiency, exchange surface area, number of working hours in a year, body temperature and average load factor; burner: manufacturer, model, installation year; thermal power exhaust: flowrate, temperature, average carbon dioxide content; kind of thermal carrier leaving the boiler: temperature and pressure should be recorded. And also for every item of equipment using thermal energy: type of thermal carrier used, hours/years of thermal demand, load factor at which thermal energy is used, rated thermal power.

As seen above, energy metering and collection of all the available data can be rather exhaustive, but in practice it is often not that detailed. The summary of our findings in the Table 2 in Appendix shows that most of observed non-energy intensive companies meter energy on facility level only use utility invoices and rarely use sub-metering, except in cases of energy audits. On the other hand, energy intensive companies often use sub-metering on department or production level.

Studies indicate that information on energy usage provides a valuable starting point for the identification and valuation of energy-related investment opportunities. We will address some of those studies later in this section. Furthermore, lacking information on energy consumption has been identified as a potential barrier for the improvement of energy-efficiency within companies. Yet empirical studies on the actual practice of gathering such information reveal very mixed evidence, as the following findings indicate. After presenting some studies indicating larger differences in corporate energy monitoring practices, several practical considerations, which may explain part of these findings, are described.

Interviews in the Belgian ceramic, cement and lime sector, which is an energy intensive sector, revealed that sub-metering seems to be common practice among sample companies (Venmans, 2014). As Venmans suggests, sub-metering has improved greatly during the last decade and is recognized as a very useful tool for finding energy efficiency opportunities and assessing the energy efficiency of new equipment ex post.

Christoffersen et al. (2006a) found in their survey of 304 Danish manufacturing companies that 61% of their sample measured energy consumption in detail regularly (Christoffersen et al., 2006b).

Companies in Ghana were found to be even less active with only ten out of 34 companies addressed in a survey measuring their energy consumption on equipment level (Apeaning & Thollander, 2013). These findings may appear surprising given the potential benefits from gathering information on energy usage, but different practical circumstances may complicate information gathering. First of all, collection of such information is likely associated with cost as well. Sorrell et al. (2011b) suggested to consider such cost as transaction cost, which implies that a rational decision maker determines the level of information gathering on energy consumption based on the tradeoff between extra cost and the benefit resulting from additional information gathering. For example, O'Driscoll et al. (2012) briefly describe a case study of the introduction of energy metering in a manufacturing plant in the Irish biomedical industry (O'Driscoll et al., 2012). The decision to equip certain machines with metering devices was made depending on the respective machine's total or average power consumption and consumption profile (i.e. whether consumption is dynamic or static) (O'Driscoll et al., 2012).

Furthermore, energy may occur in very different forms in corporate operations and, as Brunke et al.'s (2014) study of Swedish iron and steel companies suggests, measurement practices regarding different forms of energy may differ. They found that electricity consumption was measured by most of their sample companies while measurement of fuel consumption and of steam and hot water usage was less common (Brunke et al., 2014). Interviews with representatives of nine large energy intensive and non-energy intensive Swedish companies revealed that this practice may be due to the fact that some energy flows are simply difficult to measure (Sandberg & Söderström, 2003a). Extreme temperatures as in some energy intensive companies, as for example steel company, complicate measurements because of the high temperature in processes. In those cases, consumption may alternatively be calculated from other known data (Sandberg & Söderström, 2003a). They also emphasize the fact that non-energy intensive companies monitor and measure energy usage to a small extent. Even when the energy audits are made, they rarely lead to investments in energy conservations, because it is considered to be more profitable to do nothing. One similarity between energy intensive and non-energy intensive companies that they mention is that both monitor electricity better then steam, because electricity usage is easier to measure. Similar outcome can also be found in our literature review: every paper that discusses type of energy metered states that observed company meter electricity.

Sometimes it is difficult to collect all relevant data in a company that is needed for making an energy efficient decision. As Klugman et al. (2007) highlight in the example of a wood-pulp mill in Sweden, heating of most of the buildings could not be properly estimated and therefore it was not that closely examined. They also mention that the reliability for the energy data differed, as there are three sources for the information, namely data logs, measurements, and energy data given by the employees.

Yet, when measurement is difficult or too expensive, several alternative ways to determine energy usage information are available. For instance, regression based methods are one way to derive a clearer picture of the drivers underlying energy consumption patterns within a company, as demonstrated by Quinteiro et al. (2012), who describe how they supported a ceramic manufacturer with allocating energy cost and greenhouse gas emissions to different products. Moreover, simulation based approaches have been suggested to determine the impact of different influence factors on machines' energy consumption, for example, by Larek et al. (2011).

Some of the studies in our literature review also report introducing some new measurements to make energy metering more efficient. For example, in the case study of Drumm et al. (2013), the implementation of the new energy management system (STRUCTese), which is especially designed for energy intensive chemical industry, is described. The new system allows for detailed measurement and tracking of energy efficiency, which provides transparency and can help to identify potential improvements. As a result of having continuous, daily monitoring of energy consumption, the extensive list with suggestions for the reduction of energy consumption was made. Similarly, in the example of a case study in Czech Republic described in Dobes (2013a), company installed sub-meters of energy use, monitored exterior climatic conditions and temperature and humidity of interior air to control energy efficiency and to improve monitoring of the data. Based on the data gathered in the course of six months, a database of approximately twenty energy-saving options and feasible measures was created. Some of the measures were soon implemented and accounted for over 10% reduction of the total energy bill. Also, in the aforementioned study of a large biomedical manufacturing facility in Ireland (O'Driscoll, Cusack, & O'Donnell, 2012), where they developed a metering implementation strategy and installed measurement devices at each significant energy user so they could monitor the energy performance of the facility on a daily basis. This step has enabled them to perform an analysis of their energy consumption patterns.

Two typical indicators that are used in energy management are energy intensity and Specific Energy Consumption (SEC). Phylipsen et al. (1997) describe the difference between energy intensity, as an economic indicator, and specific energy consumption as a physical indicator. For both indicators the numerator measured energy use, but denominator in energy intensity is measured in economic terms, and in specific energy consumption in product units or kg/ton of final product. In our literature review, 54% of the papers presented in Table 2 in Appendix are using SEC as indicator. In most of the studies SEC is measured either in kWh/ton or kg of output, or kWh/output unit, with only one exception in the case study of a bakery from Kannan and Boie (2003) where the output did not have fixed weight or volume, so the SEC was measured in kWh/kg of processed flour.

Though these examples do not describe exhaustively the different aspects companies have to consider when deciding on their energy monitoring, they already illustrate that the decision is not straightforward and requires careful balancing of advantages and cost of gathering such information.

Allocation of energy costs

Accurate allocation of energy costs can influence decisions of a company to invest in energy management and improve energy efficiency. We differentiate between allocations based on sub-metering, which is considered the most precise method, and other calculation methods such as per product, department, meter square or per number of employees. In Table 2 in Appendix we also include column related to second stage allocation, in which energy costs are traced to final products.

As shown in the Table 2 in Appendix, we find that only six out of 45 papers (13.3%) reviewed in our systematic literature review address allocation of energy costs to departments in more detail then the allocation of SECs (Backlund et al., 2012; Brunke et al., 2014; Li et al., 2010; Rohdin & Thollander, 2006; Thollander & Ottosson, 2010a). The allocation to departments is important because of the split incentive problem, where department managers could be less motivated to save energy if department's costs are allocated based on not precise measures, as per square meter or per number of employees, instead on actual energy consumption (Thollander & Ottosson, 2010b). Only one paper from observed literature addressed second stage allocation, i.e. the allocation of energy costs from departments to products or cost centers (Fernandes et al., 1997). This is example of a small and non-energy intensive manufacturing company where activity-based costing is studied in detail with supporting measurements and calculations. As previously mentioned, sub-metering is rare in companies with similar characteristics, and in this case metering is also conducted only on facility level and further allocations are based on calculations for each department.

Traditional accounting usually classifies energy costs as overhead or running costs. For example in manufacturing, 50% costs can come from material, 5-10% from labor, the rest is overhead (Fernandes et al., 1997). Latter generally include all indirect costs such as material handling, warehousing, maintenance, quality control, engineering, setup cost, machine depreciation, and energy. The problem with traditional accounting when it comes to energy costs is, that it is assumed, that all products require same amount of energy (or other overhead costs) to the cost allocation basis. Only a few cases described detailed methods to account energy costs, which go further than the allocation of SECs. Following papers describe energy costs allocation to departments.

In their paper about energy management practices in Swedish companies, Backlund et al. (2012) found interesting results regarding allocation of energy costs in both energy intensive and non-energy intensive companies. From the observed companies, more than 60% did not allocate energy costs at all, and the rest allocated them per square meters, per product, per department or per sub-metering. Similar results were also found in the study from Rohdin and Thollander (2006), where they showed that studied non-energy intensive companies allocate energy cost evenly per square meter, per machine group or not at all. In their paper from 2014, Brunke et al. (2014) accentuate the importance of allocation of energy costs in companies. Their results, based on 23 companies in iron and steel industry, show that 65% of the companies they observe allocate their energy production per ton and 26% use sub-metering, while none of the participating companies allocate the energy cost per square meter or per employee. (Thollander & Ottosson, 2010a) also emphasize importance of sub-metering as a major prerequisite for correct energy cost allocation. In their paper they also show that majority of observed energy intensive companies use sub-metering as a method of allocating energy costs, while others allocate their energy costs per employee or per square meter, or not at all.

Sometimes an allocation problem may nevertheless occur when the flows of different forms of energy intersect, even if energy flows are measured. This will be illustrated on the example of cogeneration, which "usually refers to the simultaneous production of two energy forms (electricity, and heat in the form of steam and/or hot water) from one energy source (normally a fossil fuel)" (Rosen, 2008). That study provides an overview of different methods for the allocation of fuel consumption to two energy forms produced in a joint process, namely steam and electricity produced in a CHP (combined heat and power) system. These methods include splitting the fuel consumed according to energy or exergy content of the two energy products, splitting fuel according to the relation of the cost that would be caused by independent production of each product, defining one product as the main output and allocating to the other the incremental fuel consumption caused by cogeneration, splitting it based on economic values (such as market prices), or via arrangements among parties within the company (Rosen, 2008). Yet, selection of the allocation method is far from unimportant as Siitonen and Holmberg (2012) demonstrate in their illustrative case of a production site, at which a cogeneration plant delivers electricity and steam to a pulp and paper mill. For demonstration, they calculate the fuel cost split with the methods based on exergy, energy, cost of stand-alone production, and based on market prices. Their results show that, from the perspective of the pulp and paper mill, the profitability of an energy conservation measure (i.e., heat conservation) that can be installed by the mill differs depending on the cost allocation method applied, though from an overall perspective on the site, the outcome of the investment does not differ (Siitonen & Holmberg, 2012).

As already emphasized before, having accurate energy consumption data is important for cost accounting, but being able to track and allocate them accurately is also an important aspect that should not be neglected. Company could have perfectly accurate data on energy consumption, but using coarse methods for allocation of costs could still produce significant distortions in costs presented to management and therefore erroneous decisions regarding future investments.

Energy strategy

Having a long term energy strategy is seen as a very important step in ensuring the implementation of energy efficiency measures (Gordić et al., 2010; Rudberg et al., 2013; Thollander & Ottosson, 2010b), which includes proposition of targets for energy efficiency improvements and setting directions of energy management for the future. It has been recognized that companies seem to be more active in identifying and implementing measures specifically aiming at their energy usage when energy is considered a strategically important or core business issue, as it is stated in different surveys of Swedish companies (Brunke et al., 2014; Rohdin et al., 2007; Thollander et al., 2007; Thollander & Ottosson, 2008). On the other hand, several surveys report that many companies, even in industries with particularly high energy consumptions, such as Sweden's iron and steel (Brunke et al., 2014), pulp and paper, and foundry industries (Thollander & Ottosson, 2010b), seem to have no (longer term) strategy for energy-related topics in place.

Findings in our overview table (Table 2 in Appendix) show that only 13 papers (28.9%) include some information on formulation of energy strategies in companies. More detailed analysis of those papers reveals that most of them focus on energy intensive companies, and only two papers focus on non-energy intensive companies. On the other hand, majority of the papers (71.1%) do not mention energy strategies in observed companies at all.

For example, Brunke et al. (2014) in a study conducted on 23 companies in iron and steel sector in Sweden found out that 32% of the companies have energy policy with a long-term strategy of more than 3 years. Same number of companies have energy strategy between one and three years and others have no energy strategy or have unwritten set of goals. Ates and Durakbasa (2012) also conducted a survey on the energy intensive companies in Turkey. Results showed that only 40% of the surveyed companies have a formal energy policy and the rest of the companies stated that energy-related goals and principles are communicated orally. In the example of Backlund et al. (2012), the greatest share of the firms in category that participated in the program for improving energy efficiency in the energy intensive industries or had energy audit in the last three years does have an energy strategy and most of these firms hold a strategy of 3 years or longer: On the other hand, more than half of the firms in category that did not participate in such programs nor did conduct energy audit in the last three years lack a strategy or do not know if they have a strategy with regard to energy. Similarly, in the example of Johannson (2015), five of the observed 11 energy-intensive companies have an energy policy with a long term energy strategy of more than 3 years.

While observing non-energy intensive manufacturing companies, Rohdin and Thollander (2006) found out that three out of eight companies had long-term strategy related to energy questions. Only one more paper that dealt with non-energy intensive companies also showed that the observed company has a long term energy strategy (Hildreth & Oh, 2014).

Based on that we can conclude that far less non-energy intensive companies has clearly formulated and long term energy strategies then energy intensive companies. Specifically, only two of the papers with focus on non-energy intensive companies have long term energy strategy.

Investment criteria

Most commonly used methods for calculating profitability of energy investments are internal rate of return (IRR), net present value (NPV) and payback periods. As some authors already pointed out, strict investment criteria and short payback times are often applied in large companies, whereas in medium sized enterprises the investment criteria is less formalized (Rohdin & Thollander, 2006; Sucic et al., 2015). Too long payback period is also mentioned as one of the main reasons for not accepting and implementing energy efficiency measures in the study about 11 iron and steel companies in Sweden (Johansson, 2015).

In the example of Belgian companies in the ceramic, cement and lime industry, Venmans (2014) identified that the payback criterion was applied most commonly, followed by the IRR, while none of the companies applied the NPV (Venmans, 2014). The study further reports that some projects in the sample companies have even been decided upon without calculating any financial investment criterion at all (Venmans, 2014). They also mention how uncertainty about the future decisions justifies tighter investment criteria, i.e. the payback time smaller than the foreseeable future (Venmans, 2014).

Sandberg and Söderström (2003b) differentiate between large energy intensive companies and non-energy intensive companies and conclude that both in their sample mostly use payback method as criterion for smaller investments, and for larger investments use also other complementary methods (such as NPV and IRR) to support their decision. Several studies also report the specific requirements, such as payback periods or hurdle rates, demanded by their sample companies for an energy-efficiency project to be accepted. A survey of 23 companies in the Swedish iron and steel industry found that most of the sample companies applied payback thresholds of three years or less - some even required payback periods of less than one year (Brunke et al., 2014). Thollander and Ottosson (2010a) report similar findings for pulp and paper producers and foundries in Sweden (Thollander & Ottosson, 2010a).

Findings in their survey and interview based study of eight non-energy intensive Swedish manufacturers revealed that a lack of sub-metering and proper allocation of energy cost may be especially disadvantageous when explicit investment criteria are applied, as the lack of sufficient data may aggravate valuation of investment opportunities and thus lead to their rejection (Rohdin & Thollander, 2006). Yet, lacking information on energy usage may complicate identification of energy improvement opportunities and studies have addressed the perceived relevance of insufficient energy measurement as a barrier for energy-efficiency within companies, yet with differing results.

Other studies building on surveys and interviews also report that payback criteria are applied more commonly than NPV and IRR (Brunke et al., 2014; DeCanio & Watkins, 1998). There are some exemptions, as in the study of a ceramic tile plant in China (Huang et al., 2013), where energy efficiency improvements were made as a part of cleaner production audit. They identified various measures that can be divided in no/low cost, medium cost and high cost measures. Among the proposed measures there are also measures related to energy metering, for example enhancing the water metering for each procedure.

A survey of Swedish foundries reports that lacking sub-metering was ranked among the most important barriers (Rohdin et al., 2007). However, a survey of Swedish pulp and paper producers revealed that 'lack of sub-metering' was not considered very important as a barrier to energy-efficiency investment (Thollander & Ottosson, 2008), though it remains unclear whether the companies did not consider missing sub-metering a barrier in general, or whether it simply did not apply to them. Similarly, the iron and steel companies addressed by Brunke et al. (2014) did not consider missing information on energy consumptions to be of major concern, though the study also reports that allocation of energy cost is mostly done on a production volume basis instead of based on sub-metering (Brunke et al., 2014). The aforementioned study of companies in Ghana also did not find missing sub-metering to be considered a major barrier to increased energy-efficiency, though 24 of the 34 sample companies measured their energy only at site or building level (Apeaning & Thollander, 2013).

Energy audit

Energy audits can be defined as "a systematic procedure to obtain adequate knowledge of the existing energy consumption profile of a building or group of buildings, of an industrial operation and/or installation or of a private or public service, identify and quantify cost-effective energy savings opportunities, and report the findings" (European Parliament, 2006). They are identified as a good starting point to gain information about internal energy flows, energy consumption and losses within their processes in order understand the energy use within a company (Rohdin & Thollander, 2006; Sandberg & Söderström, 2003b).

Some companies conduct energy management projects as a part of environmental management system. In the example of energy intensive company in Norway, a technical environmental audit is scheduled every third year, and the objective of the audit is to identify new improvement measures, determine new targets and suggest further actions (Amundsen, 2000). In order to identify key issues, company also performs energy audit every three years. In study from Backlund et al. (2012) that observed 18 companies in Sweden, both energy intensive and non-energy intensive, found out that 56% of the observed companies have participated in the program for improving energy efficiency in the energy intensive industries or had energy audit in the last three years. The study conducted by Apeaning and Thollander (2013) identified that only five out of 34 observed companies conducted energy audits within the last 10 years. From the remaining companies, six of them used monitoring and targeting schemes to manage their electricity use, and four companies used benchmarks to compare their energy use against. We can also notice many other studies on energy intensive companies that report having energy audits, among others (Kannan & Boie, 2003; Klugman et al., 2007; Kong et al., 2013; Li et al., 2010; Thollander et al., 2005).

While we can note that many energy intensive companies conduct energy audits, in non-energy intensive companies it is not so widely used. Still, in the few examples of non-energy intensive companies doing energy audit, we can see that the results in terms of savings are notable. One of those studies are of a of a large Serbian car producer (Gordić et al., 2010). As a part of implementation of a new energy management system in their company, the energy audit was conducted. Before energy audit, there was no proper monitoring of energy consumption. But with energy audit the detailed analysis of the consumption was made and with precise portable measuring equipment. As a result of detailed energy audit, the possibilities for improvements could be identified and energy saving measures implemented. Overall, the reduction of 25% of total energy consumption was achieved.

Interestingly, Thollander et al. (2013) compared their findings in relation to company size and found that about half of the small, three out of five of medium-sized, and two-thirds of the large foundries had conducted an energy audit. Relating to that they also found out that foundries that had conducted an energy audit had higher energy use on average then the foundries that had not conducted an energy audit. Altogether, around 40% of the observed companies conducted energy audit.

Discussion

The common idea among studied papers is that better monitoring of energy consumption is necessary to reduce energy costs and improve energy efficiency of the company. Sandberg and Söderström (2003b) also emphasized energy monitoring and energy audits as key success factors for energy related investments. All companies in our literature review that improved measurement of energy costs also reported lowered energy costs after that investment. Even though it is possible to meter exact energy consumption in a company in detail, such practices are expensive. Because of that it is important for companies to determine how detailed energy consumption data is required to reach higher energy efficiency levels. That also means that the tradeoff between the implementation costs for metering and monitoring methods and the connected efficiency improvements has to be evaluated.

The reviewed measurement methods in energy intensive and large companies are in summary more advanced than in non-energy intensive companies and SMEs. However the remaining energy saving potential is higher in non-energy intensive than in energy intensive companies (Brunke et al., 2014) and should therefore deserve greater attention from policy makers (Trianni et al., 2013). Gruber and Brand (1991) already showed, that in SMEs information regarding their energy costs is lacking and they tend to underestimate the monetary potential of energy efficiency investments. Our analysis showed similar results (Christoffersen et al., 2006b; Kannan & Boie, 2003; Li et al., 2010; Thollander & Palm, 2015). The evaluation of case studies in energy intensive companies showed that energy is a more important topic within these companies and that the implementation rate of advanced energy management practices is higher. In a lot of cases, the researched companies reached a high energy efficiency level after the conducted improvements and following investments (Klugman et al., 2007; Kong et al., 2013; Rudberg et al., 2013; Sucic et al., 2015; Thollander et al., 2005), but only a few were already on a high efficiency level before the case studies were conducted (Li et al., 2010; Siitonen & Holmberg, 2012).

Our analysis showed that energy systems in SMEs and non-energy intensive companies are on average less complex than in energy intensive companies and that fewer different energy sources are used in SMEs and non-energy intensive companies. This simplifies the allocation of energy costs within these companies, since fewer factors have to be considered. Our results confirm the assumption that sub-metering is used in a majority of energy intensive companies (Thollander & Ottosson, 2010a) and is less distributed in non-energy intensive companies (Rohdin & Thollander, 2006). Especially in SMEs sub-metering is lacking (Apeaning & Thollander, 2013; Bunse et al., 2011; Christoffersen et al., 2006b; Thollander et al., 2015). The less energy-intensive and smaller the company, the less energy is used in production processes (Thollander et al., 2015).

Therefore in those companies measurement in support processes is more important and should be done with more detail than in energy intensive companies where support processes only cause a minor part of the energy costs. For SMEs and non-energy intensive companies it pays off to segregate different support processes (e.g. lightning, cooling, heating) and measure these processes in detail (Dobes, 2013a). Companies, where production processes account just for a smaller share of the energy costs, benefit more from continuous measurements and investments in support processes and on facility level (Aflaki et al., 2013), than from detailed measurement of energy consumption in production processes. For companies, where the production processes play a more important role within the total energy costs, more advanced sub-metering in production processes should be conducted. Kannan and Boie (2003) showed that sub-metering in small companies is an effective way to reduce energy costs, Dobes (2013a) and Gordić et al. (2010) had similar results in medium sized companies.

Detailed information regarding further accounting methods for measured energy data is scarce in the analyzed papers. Only in three papers (Dobes, 2013a; Fernandes et al., 1997; Sucic et al., 2015) energy cost centers

(ECC) or activity based costing (ABC) were described in detail. In their case study Fernandes et al. (1997) describe the implementation of ABC method on allocation of energy costs. They describe in detail on the example of a company how are costs calculated on resource and activity level, and later distributed in order to identify the total costs per product. In two more studies a similar approach was used, by allocating the energy costs to energy cost centers (ECC) (Dobes, 2013a; Sucic et al., 2015). ECC can be any department, section or machine that uses energy; all consumption related to these cost centers is allocated and performance indicators are defined for each cost center. Similarly to ABC, this also helps to identify where exactly energy was spent. To implement accounting methods like energy cost centers or activity based costing is the logical next step after the implementation of sub-metering, to allocate and monitor energy costs on a regular basis. Therefore it can be assumed that similar methods are implemented in most companies using sub-metering in order to use the sub metered data and calculated SECs to allocate energy costs and to identify cost saving potential. The analysis shows that increased knowledge on internal energy consumption always leads to improvement opportunities and in many cases to investments in energy efficiency, implementation of new tools and strategic energy management decisions. Many of the suggested measures to reduce energy consumption require zero or low cost investments (Aflaki et al., 2013; Dobes, 2013a; Thollander et al., 2015) and result in direct monetary savings. This result has a high relevance for SMEs, where investment budgets are smaller and investment planning is conducted for a shorter time period (Apeaning & Thollander, 2013). In large companies investments which require more capital are more often implemented (Aflaki et al., 2013; Dobes, 2013a; Klugman et al., 2007). Differences can also be found between non-energy intensive companies and energy intensive companies. Energy intensive companies make more long range investments, such as power plants or furnaces, with payback times up to 30 years. Non-energy intensive companies have more changes in their production (e.g. new products lines, shout down, move) and therefore need more flexibility and shorter payback times (Sandberg & Söderström, 2003b). Another issue in non-energy intensive companies is that material and energy flows are estimated, once a new factory is built, but in many cases this data is not used later on.

Several of the analyzed papers emphasized that the measurement of energy costs can enhance energy investments. Except of one company, none of the studied companies in Rohdin and Thollander (2006) used sub-metering, they either used allocations per square meter, machine group or no metering at all. This leads to problems in quantifying cost savings and hesitations in investment decisions. Especially large companies have strict payback criteria for investments regarding profit and payback time of investments (Rohdin & Thollander, 2006). Many energy investments are not implemented because they either extend defined payback times (which is on average three years in most of companies (Venmans, 2014)) or internal rate of return (IRR), with high minimum return rates, is used as criteria for investments (Brunke et al., 2014). For example the companies in Thollander et al. (2015) only considered investments with an IRR of more than 15%. More energy investments are considered, if net present value (NPV) is used as investment evaluation (Bunse et al., 2011). The advantage of NPV in terms of energy investments is, that discount rates are considered, as well as the total lifetime of the investment (Sandberg & Söderström, 2003b). Short payback requirements lead to safe investments, neglecting profitable energy investments. Energy audits are therefore important in order to constantly review the recent status and identify energy saving potential. Another aspect of strict investment criteria, which hampers the implementation of energy investments, is that other benefits of energy efficiency investments, such as better working conditions, greater staff motivation, raw material savings and reduced emissions are often not considered, because they are more difficult to quantify (Sandberg & Söderström, 2003b). Sivill et al. (2013) recommend companies to determine their energy performance objectives on economic, environmental and social levels and turn these into quantifiable and accessible objectives.

Conclusion

In this systematic literature study, we have addressed the problem of energy metering and management practices of manufacturing companies and reviewed the empirical literature on the subject. The purpose of the review was to provide a comprehensive overview of practices, with emphasis on the difference between energy intensive vs. non-energy intensive, and small and medium enterprises vs. large companies. Our search process yielded 45 papers in 19 journals. Three journals published more than half of all studies: *Journal of Cleaner Production, Applied Energy* and *Energy*.

The majority of the relevant papers had energy intensive companies in main focus, 33 of them (73.3%). Only 17.8% focused on non-energy intensive companies. Other two categories include papers with both energy intensive and non-energy intensive companies, and papers where such distinction is not known. It is shown that non-energy intensive companies monitor and measure energy usage to a small extent, and even when the energy audits are made, they rarely lead to investments in energy conservations, because it is considered to be more profitable to do nothing. 54% of the papers in our literature review are using specific energy consumption (SEC) as energy indicator. We also find out that only six out of 45 papers (13.3%) reviewed in our systematic literature review address allocation of energy costs to departments in more detail then the allocation of SECs, while only one reviewed paper addressed second stage allocation, i.e. the allocation of energy costs from departments to products or cost centers. Similar finding can be seen related to energy strategy, where we can conclude that far less non-energy intensive companies have clearly formulated and long term energy strategies then energy intensive companies.

Further research should investigate how companies, which implemented advanced energy measurement methods, profit from the measured data during a longer period of time and how the measured data influences their decisions. Most of the detailed case studies were conducted in large and energy-intensive companies, therefore further research should include detailed case studies in SMEs, which are planning to improve the measurement of energy costs in their company. These case studies should derive more information, how energy consumption and related costs are monitored in these companies.

Another limitation of this paper is that regional research emphases were found in Scandinavia, China and Europe, but case studies in different regions are lacking. To gain information about energy measurement in other regions is as important as to get more information from less developed countries, since case studies were mostly conducted in developed economies.

Companies benefit to a large extent from detailed measurements on energy consumption. The potential cost savings due to more accurate measurements are often underestimated and therefore just a small share of companies is measuring their energy consumption with high accuracy. This systematic review reveals that the implemented measurement methods vary from inefficient measurement methods to detailed sub-metering in real time. The implementation rate of detailed sub-metering is higher in large and energy intensive companies. Nonetheless even in these kinds of companies sub-metering is often lacking and cost saving potential is left unexploited. This points to an even larger unexploited cost saving potential in small and medium sized enterprises and non-energy intensive industries. The findings point out that most literature concerns energy intensive and large companies. The most interesting findings are based on the few studies that cover non-energy intensive companies. These use coarse methods for measuring and allocating energy costs. The majority of companies do not allocate energy costs at all, a minority of companies uses sub-metering to track energy consumption within the company, and others allocate costs roughly, such as per square meter or per employee. There are almost no studies that provide a more nuanced description of measuring and allocating energy costs, for example by investigating specific cost allocation bases, the accuracy of cost allocations, and differentiating between first-stage and second stage allocation. The literature review suggests that the idea of Gruber and Brand (1991) that SMEs tend to underestimate the monetary potential of energy efficiency improvements was correct, given the small number of small and medium sized companies in the sample. The overall impression is that many non-energy intensive companies may lack much of the information necessary for energy management, for example, for identifying opportunities for improving energy efficiency, for evaluating the financial benefits and costs of energy efficiency improvement investments, and for holding managers accountable for energy efficiency.

Appendix

Table 2. Detailed findings of the literature review

Authors	**Year**	**EI /NEI**	**Company size focus**	**SEC**	**Allocation of energy costs**	**Addressing second stage allocation**	**Measuring energy consumption**	**Types of energy measured**	**Addressing energy strategy**
	Summary of details on metering			**Investing in efficiency improvements**			**Criteria for energy-related investments**		
Afkhami, Akbarian, Beheshti, Kakaee, Shabani	(2015)	EI	Large	Per kg of final product	Not specified	No	Yes	Electrical, thermal energy	Not specified
	Metering largest consumers in detail			Some equipment repaired or replaced with new and more efficient solutions			Not specified		
Aflaki, Kleindorfer, de Miera Polvorinos	(2013)	NEI	Large	Not specified	Not specified	No	Yes	Electricity and heat consumption	Yes
	Facility-wide measurement system			A master plan developed containing around 200 projects, which were split into two categories: 1st with low investments, direct benefits and short payback time, 2nd with higher risk and longer payback times			For each of the projects conducted an assessment of projected energy savings, carbon savings and cost savings. Also expected to satisfy capital expenditure limits and required payback periods.		
Alkaya, Demirer	(2014)	EI	SME	Per ton of final product	Not specified	No	Yes	Energy sources: natural gas and electricity, measuring: water, total energy, natural gas, steam generation	Not specified

	Not specified			Renovation and improvement of equipment			Not specified		
Amundsen	(2000)	EI	Diverse	Per kg of final product	Not specified	No	Yes	Water, energy consumption	Yes, technical environmental audit every three years, aimed to identify new improvement measures, determine new targets and to suggest actions for environmental program
	Monitoring system database which logs water and energy consumption for each production department			1. Weekly calculation of Environmental Performance Indicators (EPI) and corrective actions if needed, 2. several energy efficiency improvement measures, considerable operational savings every year, 3. and 4. corrective actions based on EPI, key statistics and consumption figures			Not specified		
Apeaning, Thollander	(2013)	EI	Not specified	Not specified	Not specified	No	Yes	Electricity	Not specified
	24 companies metered electricity use at both site and building levels, remaining metered at equipment level			6 firms used monitoring and targeting schemes to manage their electricity use, 4 kad benchmarks to compare their energy use against, 5 conducted energy audit within the last 10 years			Not specified		
Askounis, Psarras	(1998)	EI	Large	Per unit of final product	Not specified	No	Yes	Electricity, fuel oil, steam, water	Not specified
	Sub-metering regularly on the department level			Using energy monitoring and targeting system to generate detailed reports			Not specified		

Ates, Durakbasa	(2012)	EI	Diverse	Per ton of final product	Not specified	No	Not specified	Not specified	40% have formal energy policy
	Not comparable - considering metering as part of energy management activities, at least 24%			80% implemented an energy efficiency project within the previous 2 years			Not specified		
Backlund, Broberg, Ottosson, Thollander[4]	(2012)	Both	Not specified	Not specified	X: 60% not at all, 10% sub-metering, 10% m2, 10% per product, 10% per department, Y: 63% not at all, 13% other, 13% sub-metering, 13% per m2	No	Not specified	Not specified	X: most of them have energy strategy for more than 3 years, Y: 50% don't have energy strategy
	Not specified			56% of the companies have participated in the program for improving energy efficiency in energy-intensive industries or had energy audit in the last three years			X: 60% 2-3 years pay-off criteria, 40% lack criteria, Y: 50% lack criteria or don't know, 26% 2-3 years, 25% 4+ years		
Beecroft	(2007)	EI	Large	Per ton of final product	Not specified	No	Yes	Electricity, fuel	No longer use power specific action plans, everything is integrated into overall plant improvement plan

[4] X – firms that participated in energy efficiency programs or conducted an energy audit in the last three years, Y - firms that have not participated in energy efficiency programs nor conducted an energy audit in the last three years

	Metering largest consumers and incoming power			Optimization of process controls and plant standard operating procedures as a result of more accurate tracking			Not specified		
Boutaghriout, Hamouda, Smadi, Malek	(2016)	EI	Not specified	Per kg of final product	Not specified	No	Yes	Natural gas, electricity	Not specified
	Not specified			Not specified			Not specified		
Brunke, Johansson, Thollander	(2014)	EI	Diverse	Not specified	65% of participating companies allocate their energy consumption per ton, 26% use sub-metering, none use per square meter or per employee	No	Yes	100% of companies measure electricity, 70% measure fuel and 60% measure steam and water	32% with a long-term energy strategy (>3 years), 32% (1-3 years), 36% no policy
	17% annually or quarterly, 63% monthly or weekly, 20% daily metering			13% of companies train and promote energy efficiency on a regular basis			investments based on payback time (19, only 4 for 3 years and longer), internal rate of return (3) and net present value (1)		
Christoffersen, Larsen, Togeby	(2006b)	Not specified	Diverse	Not specified	Not specified	No	Yes	61% regularly measuring energy consumption in detail	Not specified
	Not specified			65% are implementing specific energy-saving projects, 44% seeking to actively involve the employees in the energy-saving work			Not specified		

Dobes	(2013b)	EI	Diverse	Not specified	Not specified	No	Yes	Only total use of electricity and natural gas	Not specified, the investments are made as a result of energy efficiency project
	Not specified			Installed sub-meters of energy use, exterior climatic conditions, humidity of interior air -> implemented saving measures			Payback period		
Dongellini, Marinosci, Morini	(2014)	NEI	Large	Per unit of final product	Not specified	No	Yes	Gas, electricity	Not specified
	Gas and electricity meters on a building level			Proposed energy saving measures, feasibility study, estimation of energy savings			Payback time of less than 5 years for energy saving actions		
Drumm, Busch, Dietrich, Eickmans, Jupke	(2013)	EI	Large	Per ton of final product	Not specified	No	Yes	Yes	No, this is first time - energy management system implementation
	Steam, electricity on consumer level			Based on continuous daily metering, the possible improvements were identified, and some of them implemented			Feasibility and profitability		
Fernandes, Capehart, Capehart	(1997)	NEI	SME	Not specified	Activity based-costing, First stage: sub-metering, per square meter, Second stage: number of hours consumed, number of setups	Yes	Yes	Electricity, fuel	Not specified

	Metering on facility level, but further allocations based on calculations for each department			Not specified			Not specified		
Gordić, Babić, Jovičić, Šušteršič, Končalović, Jelić	(2010)	NEI	Large	Per unit of final product	Not specified	No	Before: yes, but no detailed data, Audit: yes	Audit: steam, hot water, electricity, natural gas, compressed air, propane, demi water, water	Not specified
	Audit: portable flow meters, ultrasonic thickness gauge, 3-phase power analyser, infrared camera, infrared thermometer, anemometer, laser photo/contact tachometer, flux-meter			Implementation of energy saving measures as a result of energy audit results -> 25% reduction of total energy consumption			Before: only low budget projects (less than 10.000e), After: technical and economic feasibility, payback time		
Hildreth, Oh	(2014)	NEI	Large	Not specified	Not specified	No	Yes	Energy and water use on a monthly basis for all facilities	Yes, 10 year goals
	Utility invoice at site and metering at business units			Yes, investments in energy efficiency and energy conservation, regular meetings to improve efficiency and evaluate progress			Prioritization of projects based on return on investment and the probability of successful implementation -> developing project implementation plan		
Huang, Luo, Xia	(2013)	EI	Large	Per ton of final product and per unit of final product	Not specified	No	Yes	Water, electricity, fuel	Not specified
	Metering on the process level			Enhancing water metering as part of measures recommended by cleaner production audit			No/low cost, medium and high cost measures		
Johansson	(2015)	EI	Diverse	Not specified	Not specified	No	Yes	Not specified	5 companies have long term strategy of more than 3 years

	Not specified			Some of them introduced sub-metering and new equipment to improve energy efficiency			Payback period, profitability		
Kannan, Boie	(2003)	EI	SME	Per kg of processed flour	Not specified	No	Yes	Electricity and furnace oil consumption	Not specified
	Not specified			Replaced some machines, conduction of annual energy audits -> reduction of 6.5% of total energy consumption			Life cycle analysis, payback period		
Kirabira, Nalweyiso, Makumbi	(2014)	EI	SME	Per kg of final product	Not specified	No	Some	Oil, fuel, biomass, electricity	Not specified
	Lacking meters to monitor energy utilization for the main production systems - estimation of electricity used, biomass also not measured			Not specified			Not specified		
Klugman, Karlsson, Moshfegh	(2007)	EI	Large	Per ton of final product	Not specified	No	Yes	Electricity, process heat	Not specified
	Electricity and process heat from data logs, generic processes and waste-water heat are measured, other energy data given by staff			Improved some machines, updated them to save energy etc.			Payback period of 2 years		
Kong, Price, Hasanbeigi, Liu, Li	(2013)	EI	Large	Per ton of final product	Not specified	No	Yes	Coal, fuel, electricity, thermal energy	Not specified
	For energy audit purposes they used statistical reports, plant energy bills, field measurements and discussed with plant operators			Not specified			Payback period, profitability		

Li, Li, Qiu, Xu	(2010)	EI	Large	Per unit of final product	allocation on department level	No	Yes	Electricity, water and fuel (coal, kerosene, diesel and heavy oil)	Not specified
	Metering for production lines			Energy conservation projects based on the results of energy audit			Not specified		
Martin, Muûls, De Preux, Wagner	(2012)	Not specified	Large	Not specified	Not specified	No	Not specified	Not specified	Cca 66% have targets for energy consumption (13% of that have expenditure targets, other quantity targets)
	Not specified			Not specified			Payback time of 3-5 years		
Muller, Marechal, Wolewinski, Roux	(2007a)	NEI	Large	Not specified	Not specified	No	Yes	Fuel, electricity	Not specified
	Utility bills, for electricity daily metering			Not specified			Payback period		
O'Driscoll, Cusack, O'Donnell	(2012)	EI	Large	Not specified	Not specified	No	Yes	Electricity	Not specified
	Implemented detailed energy metering strategy, metering energy at several levels			Yes, implemented detailed energy metering strategy, metering energy at several levels			Not specified		
Ozturk	(2005)	EI	Diverse	Per kg of final product	Not specified	No	Yes	Electricity	Not specified

	For electricity metering, for coal, fuel oil and LPG utility bills			Not specified			Not specified		
Rohdin, Thollander	(2006)	NEI	Diverse	Not specified	per square meter, per machine group or not at all	No	Yes	Not specified	3 have long term strategy, 2 of them implemented more than companies that lacked such strategy
	Only one has sub-metering			Not specified			Payback criteria, large companies more strict investment criteria with short pay-back times		
Rudberg, Waldemarsson, Lidestam	(2013)	EI	Large	Per ton of final product	Not specified	No	Yes	Electricity, steam, water	Not specified
	No detailed data			Energy saving programs, decreased energy use by 13%			Payoff criteria, risk factor		
Sa, Paramonova, Thollander, Cagno	(2015)	EI	Large	Not specified	Not specified	No	Yes	Electricity, water, heat	Yes, not defined how long
	Sub-metering for departments			Yes, implemented different projects			Identify and prioritize future projects based on improved energy efficiency and pay-off (less than 3 years)		
Sandberg, Söderström	(2003a)	Both	Large	Not specified	Not specified	No	Some	Electricity better then steam, because electricity usage is easier to measure	Not specified
	In some EIC hard because of high temperatures, so the consumption is calculated instead. In NEIC meter to a small extent.			Not specified			EIC: for smaller investments pay-off method and common sense, with large investments more calculation methods. NEIC: low priority of energy investments because energy costs are small part of total costs, mostly use pay-off method.		

Sathitbun-anan, Fungtammasan, Barz, Sajjakulnukit, Pathumsawad	(2015)	NEI	Diverse	Per ton of final product	Not specified	No	Yes	Electricity, steam	Not specified
	No detailed data			Not specified			Not specified		
Sivill, Manninen, Hippinen, Ahtila	(2013)	EI	Large	Not specified	Not specified	No	Yes	Electricity, fuel and primary heat	Not specified
	Monthly and annual data at company, site and department level			Not specified			Not specified		
Sucic, Al-Mansour, Pusnik, Vuk	(2015)	EI	Large	Per ton of final product	Not specified	No	Yes	Electricity, fuel	Not specified
	Sub-metering on energy cost center level			Not specified			Not specified		
Thollander, Karlsson, Söderström, Creutz	(2005)	EI	SME	Per ton of final product	Not specified	No	Yes	Electricity, LPG, district heating	Not specified
	On production and support process level			Proposed measures as a result of energy audit			Not specified		

Thollander, Ottosson[5]	(2010b)	EI	Diverse	Not specified	sub-metering (65% F, 66% P&P), not at all (30% F, 21% P&P), per square meter (5% F, 8% P&P), per number of employees (0% F, 5% P&P)	No	Yes	Not specified	P&P: 22% have no long-term energy strategy, 58% 5+ years strategy, F: 53% no strategy, 27% 5+ years strategy
	65% F and 66% P&P use sub-metering			Not specified			Most of the companies use pay-off criteria of 3 years and less, and 25% F and 8% P&P lack criteria		
Thollander, Backlund, Trianni, Cagno	(2013)	EI	Diverse	Not specified	Not specified	no	Not specified	Not specified	47% don't have long term energy strategy
	Not specified			Not specified			Not specified		
Trianni, Cagno, Thollander, Backlund	(2013)	EI	Diverse	Not specified	Not specified	No	Not specified	Not specified	Not specified
	Not specified			Not specified			Not specified		
Venmans	(2014)	EI	Diverse	Not specified	Not specified	No	Yes	Not specified	Not specified

[5] F – foundry, P&P – pulp and paper industry

	Energy sub-metering in 14 companies, 2 plants with only one gas meter			Not specified			Payback time of 3 years		
Virtanen, Tuomaala, & Pentti	(2013)	EI	Large	Per ton of final product	Not specified	No	Yes	Fuel, steam, electricity	Yes, details not specified
	Sub-metering on plant and production unit level			Not specified			Not specified		
Wu, Li, Liu, Zhang, Zhou, Zhao	(2012)	EI	Large	Per ton of final product	Not specified	No	Yes	Steam, electricity, water	Not specified
	Utility and smart meters			Yes, implementation of real-time online monitoring system			Not specified		
Yacout, El-Kawi, Hassouna	(2014)	EI	Large	Per ton of final product	Not specified	No	Yes	Power, steam	Not specified
	Daily, on department and plant level, only total steam consumption, no steam flow meters			Based on metering, the possible improvements were identified and some of them implemented, monthly reduction in power consumption of 3.9%			Not specified		
Zolkowski, Nichols	(2013)	EI	Large	Not specified	Not specified	No	Yes	Not specified	Not specified
	Data loggers, current transformers, meters			Not specified			Savings, risk		

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