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SHORT SURVEY PAPER

Improving environmental management accounting: how to use statistics to better determine energy consumption

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Abstract The accounting literature voices increased concerns about sustainability issues. Environmental performance as one dimension of sustainability includes among others the management and control of energy. Energy is a key production factor to which the stakeholders of a firm pay increased attention. Since energy has a significant influence on the economic costs and the environmental footprint of firms, management accounting is under growing pressure to better monitor and control energy costs. As a consequence, management accounting needs to develop energy management systems which control energy consumption and aim to reduce energy costs which in turn diminish a firm's environmental impact and thus improve corporate reputation. One of the most important elements for energy management systems is an effective and cost-efficient measure of the energy consumption. However, firms and their management accounting departments, respectively, are still struggling to develop any cost-efficient approach for measuring energy consumption. That is why we suggest a statistical approach to easily and cost-efficiently measure energy utilization which in turn provides information input to improve environmental management accounting (e.g., cost allocations). We demonstrate our approach for a firm from an energy-intensive industry. The approach allows to distinguish more efficient from less efficient production units. We derive implications from this measurement approach for environmental management accounting and environmental management control systems.

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1 Introduction

It is without doubt that sustainability is nowadays a key concern for the management and the stakeholders of firms. The well-known "Brundtland Report", which was released by the United Nations World Commission on Environment and Development in 1987, defines sustainable development as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (WCED 1987, p. 43). Firms must engage in sustainability considering the demand and interests of the various stakeholders in the firm's environmental corporate social responsibility (e.g., Bansal and DesJardine 2014; Poser 2012; Schultze and Trommer 2012). As a consequence, in the recent past accounting research began to examine sustainability issues and how financial as well as management accounting practices may contribute to the sustainability of firms (e.g., Albelda 2011; Bebbington and Gray 2001; Gond et al. 2012; Gray and Bebbington 2000; Guenther et al. 2016; Hopwood et al. 2010; Poser 2012; Schaltegger 2010; Burritt and Schaltegger 2010; Trianni et al. 2016a; Virtanen et al. 2013). The research ranges from determining what sustainable development means for the accounting profession to developing a set of instruments which improve the ability of managers to better cope with the challenges of improving the environmental performance of the firm (e.g., Burritt and Schaltegger 2010; Gray 2010; Spence and Rinaldi 2012; Virtanen et al. 2013; see for an overview of this literature Guenther et al. 2016; Schultze and Trommer 2012; Schulze et al. 2016). For example, sustainability-oriented performance measurement systems have been developed (Bebbington 2009; see for an overview Searcy 2012) and approaches like the sustainability balanced scorecard or sustainability management control try to bridge the gap between a sustainability-oriented corporate strategy and the design of sustainability information management (e.g., Figge et al. 2002; Schaltegger 2010; Virtanen et al. 2013). A key characteristic of these approaches is to develop key performance indicators that reflect and measure strategically relevant sustainability issues (Burritt and Schaltegger 2010; May et al. 2015; Virtanen et al. 2013).

However, research as well as management practice note that developing pragmatic key performance indicators and tools for sustainability accounting and performance measurement are still real challenges and so far have remained at an early stage of development (e.g., Burritt 2004; May et al. 2015; Schultze and Trommer 2012; Virtanen et al. 2013). That is why a clear approach to sustainability accounting is still lacking. Specifically, the understanding of how firms operationalize sustainable development in detail is very limited (Bansal 2005; Schaltegger and Burritt 2010; Virtanen et al. 2013). One of the key reasons for this lack of operationalization is the challenge for firms how to measure the usage of input factors (e.g., energy) that are relevant for assessing and controlling sustainable development in an effective and cost-efficient way (e.g., May et al. 2015; Trianni et al. 2016b; Virtanen et al. 2013).

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Drawing upon this deficiency, the specific aim of our paper is to integrate the sustainability issue of energy efficiency measurement in the management accounting literature. Energy management has been the subject of considerably increased attention with regard to policy formulation (e.g., Thollander and Ottosson 2010; Schulze et al. 2016). For example, the European Council has made a commitment to increase energy efficiency by 20% by 2020 (EC 2009). It is acknowledged that economic activity is the principal source of unsustainability due to its significant resource usage (e.g., Gray 2010; Heffels et al. 2012; Virtanen et al. 2013). Consequently, an environmental management accounting needs better tools to improve internal decision making as well as eco-efficiency and for a better resource allocation especially with regard to energy consumption (Bierer and Götze 2013; Layer and Strebel 1984; Trianni et al. 2016b). Eco-efficiency claims that it is possible to increase productivity and thus reduce costs while simultaneously improving environmental performance (Bebbington 2001; Burnett and Hansen 2008; Fonseca and Jabbour 2012). Therefore, it is essential for an environmental management accounting system to identify and report physical information with regard to the use and flow of materials, water, wastes, and energy, which then can be related to monetary information like environmental costs, earnings, and savings (Bartolomeo et al. 2000; Burnett and Hansen 2008; Virtanen et al. 2013). However, theoretical contributions and empirical case studies concerning actual energy management practices and their relationships to strategic and financial issues are more or less inexistent (Thollander and Ottosson 2010; Schulze et al. 2016; Worrell et al. 2009). In general, this lack of knowledge results in calls for an interdisciplinary and collaborative research agenda advancing sustainable solutions (McCormick et al. 2016).

That is why we provide a specific approach to better determine the energy consumption of firms. Especially for firms in energy-intensive industries it is a must to better and in detail assess the energy consumption of their specific production facilities to support energy efficiency measures (Jung et al. 2001; Posch et al. 2015; Schulze et al. 2016). Energy itself is important because its production is a major cause of carbon emissions. Moreover, the costs of energy consumption (e.g., oil) have increased significantly in the recent past. Thus, to reduce energy consumption and related energy costs firms need to implement an energy management that exploits energy efficiency potentials and creates significant cost savings (Schulze et al. 2016). However, firms are often faced with a trade-off since the detailed collection of energy consumption comes with high investment and operating costs (e.g., for the installation and observation of meters; Jung et al. 2001; Layer and Strebel 1984; Thollander and Ottosson 2010; Trianni et al. 2016a). Especially for small and medium sized enterprises case studies and surveys show that still many barriers to improved energy efficiency and energy management systems exist (e.g., Rohdin and Thollander 2006; Thollander and Ottosson 2010; Trianni et al. 2016b). Because of lack of time, other investment priorities and the pressure for low operating costs firms refrain from submetering and a more detailed observation of energy consumption. For instance, Rohdin and Thollander (2006) as well as Thollander and Ottosson (2008, 2010) identify in their case-studies and surveys of energy-intensive as well as non-energy intensive firms a number of factors that inhibit the implementation of such improved energy consumption measures. They derive the lack of time, cost of hassle, other priorities and the

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cost of obtaining information about energy consumption as the top-named obstacles. As a consequence, the companies in these studies had no submetering of energy at their sites, which resulted in problems when quantifying detailed energy consumptions and as such potential energy savings (Rohdin and Thollander 2006; Thollander and Ottosson 2010; Trianni et al. 2016b). In addition, because of such a lack of a detailed energy consumption measurement, firms apply an inadequate allocation of energy costs at the plant level. As a result, Thollander and Ottosson (2010) conclude that if energy costs are not allocated on the basis of actual energy use, but instead, for example, per square meter or per number of employees, then the commitment of the responsible managers to save energy will most likely be less ambitious. Interestingly, the case company in our study also demonstrates a similar behavior. The case company stems from an energy-intensive industry. Because of its extremely high energy consumption the case company would need highly specialized meter systems. This in turn would lead to significant investment and maintenance costs which the company is not willing to afford.

Based on this observation that firms often refrain from a detailed physical collection of energy consumption data for a number of reasons, our study contributes to the literature on environmental management accounting by providing an approach to better determine energy consumption based on already existing data in the accounting system. Using statistical analyses we show that it is possible to derive the energy consumption at each point of consumption without any additional installation or operating costs needed to measure the energy consumption. Thus, firms can more easily and cost-efficiently detect their major energy guzzlers and take actions to improve their energy performance and eco-efficiency. Since our approach uses existing data that are collected anyway in firms, our approach is not time-consuming and does not need any additional investment or operating costs. In addition, since the installation of additional or different meters can be avoided, our approach will not lead to any interruptions of the manufacturing process. As such, the management of firms should be more inclined to follow such an approach instead of any other more time-consuming and costly alternatives. Furthermore, our approach shall contribute to a faster and better allocation of energy costs. We show the applicability of our approach by using real data from a big German printing plant.

The rest of the paper is structured as follows: the next section presents the background of environmental management accounting with regard to challenges for energy efficiency measurement. In the following section, we describe and present our approach for determining eco-efficient energy consumption measurement. Section 4 presents implications of such an easy and cost-efficient measurement approach for environmental management accounting tools and environmental management control systems. The last section concludes and derives avenues for future research.

2 Background and challenges for an efficient energy measurement

Research so far has dealt with several different aspects concerning potential links between sustainability and accounting. A strong emphasis has been on the relationship between environmental performance and corporate performance which is an impor-

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tant relationship since companies are increasingly forced to be both profitable and environmentally responsible (Schultze and Trommer 2012). Endrikat et al. (2014) and Schultze and Trommer (2012) provide an extensive review of this kind of literature. This literature emphasizes that the empirical research in this field uses a large variety of environmental performance measures (e.g., Poser 2012). Building upon classification by Jung et al. (2001), Endrikat et al. (2014) and Schultze and Trommer (2012), these measures can be classified into a strategic and operational category. The strategic category encompasses a firm's attitudes and objectives regarding environmental responsibility as well as environmental management structures and processes. The operational category refers to input (e.g., energy), process (e.g., use of new technologies), output (e.g., waste, emissions), and outcome (e.g., impacts on stakeholders, environmental liabilities) measures. In our study, we focus on the operational input, i.e., energy.

However, the measurement and management of energy consumption and energy efficiency, respectively, involves several complexities which impede the effective use of management control systems to influence the motivation and ability of employees to work toward the aims of sustainable development (Trianni et al. 2016b; Virtanen et al. 2013). These complexities result from the fact that firms may use several different energy sources (e.g., coal, oil, electricity) simultaneously which in turn produce different forms of other energy (e.g., electric and thermic energy). Moreover and more important, energy consumption is normally characterized by temporal, capacity-related, and quality-related demand/supply fluctuations because of volatile needs and frequent changes of process conditions during the day (Bierer and Götze 2013). This volatility in usage over time (different demands over time, often changing process conditions) turns the detailed measurement of energy consumption into a diverse and complex task. However, the detailed measurement of energy consumption is highly relevant for several reasons: first, energy is a very important production factor, which becomes more expensive. Thus, there is a high need to control these costs. Energy efficiency is a ratio between the total energy used and the useful output of a process measured in physical units (Virtanen et al. 2013). While the output is easy to measure, it is very difficult to assess the energy used. In this context, machines for example behave differently with regard to their energy consumption. If no detailed measurement is provided, it is not possible to identify more efficient machines compared to less efficient machines. Second, energy costs are usually manufacturing overhead which is allocated to production units via general allocation bases like machine or labor hours (e.g., Bierer and Götze 2013; Schulze et al. 2016). A more detailed measurement of energy consumption would allow for a better and fair assignment of costs to cost objects. In many organizations with multiple departments, inadequate energy cost allocation may result in slack energy management (Rohdin and Thollander 2006; Thollander and Ottosson 2010). One approach to better and in detail measure and thus allocate energy consumption would be by submetering which is the implementation of a system that allows a firm for individual measured utility usage. However, such a submetering system usually entails high investment and operating costs which firms are often not willing to provide. In addition, after the submetering system is installed, it takes a lot of time to collect the relevant data from the submetering system. Thus, although a more detailed measurement of energy consumption leads to a better allo-

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Table 1 Sample data on the total energy consumption in 15-min units

Date	Starting time[a]	End time[b]	Energy consumption (in kw)
1/1/2016	0:00:00	0:15:00	1017
1/1/2016	0:15:00	0:30:00	2053
1/1/2016	0:30:00	0:45:00	1879
1/1/2016	0:45:00	1:00:00	878
…	…	…	…

[a] For the starting times "≥" is assumed
[b] For the end times "<" is assumed

cation of costs, in practice it is not done because of cost-efficiency and time-efficiency reasons (Bierer and Götze 2013; Thollander and Ottosson 2008, 2010).

The existing management accounting literature does not provide any approaches to overcome this dilemma. The emphasis is mostly on strategic issues of environmental and energy management accounting and cost accounting theories have neglected energy and the costs induced by energy so far (e.g., Bartolomeo et al. 2000; Bebbington and Larrinaga 2014; Bierer and Götze 2013). Therefore, we suggest an easy and cost-efficient improvement for energy consumption measurement which in turn allows firms to better allocate and control energy costs.

3 An approach for efficient energy consumption measurement

Our approach uses existing data and statistical analyses to measure energy consumption. For illustrative purposes we directly describe the approach for the case company which stems from the paper, printing, and pulp industry in Germany. The case company produces paperbacks (printing and binding), i.e., the output runs through different production steps and results in a rather similar output. The printing industry is known for its highly energy-intensive production combined with high production volumes (e.g., Posch et al. 2015; Thollander and Ottosson 2008). Thus, this industry is a natural candidate which is often used for the analysis of environmental management accounting issues (see for example Posch et al. 2015; Thollander and Ottosson 2008; Virtanen et al. 2013). In general, this industrial sector uses more energy than any other end-use sector, consuming about one-half of the world's total delivered energy (EIA 2015). As a result, considering its high annual energy consumption and high energy costs the firm was an appropriate candidate for our study. In addition, the management of the case company constantly aims at improving energy-efficiency.

Companies in such energy-intensive industries usually compile quarter-hourly load profiles[1] of energy consumption ("Wirkleistung"), in which the energy consumption for the entire company and/or different production plants (but usually with only one meter for each production plant installed) is recorded and stored precisely in 15-min intervals (Table 1).

[1] A load profile is a chart illustrating the variation in demand/electrical load over a specific time. An electrical load is an electrical component or portion of a circuit that consumes electric power.

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Table 2 Sample data on the running times of the machines

Machine	Starting date	End date	Starting time	End time
1	1/1/2016	1/1/2016	0:00:00	0:11:39
1	1/1/2016	1/1/2016	0:14:02	0:18:47
1	1/1/2016	1/1/2016	0:33:12	6:13:23
…	…	…	…	…
4	1/1/2016	1/1/2016	0:00:00	4:17:44
…	…	…	…	…
10	1/1/2016	1/1/2016	0:00:00	0:04:06
10	1/1/2016	1/1/2016	1:13:54	12:06:04
…	…	…	…	…

Companies automatically save the running times of all their machines, or at least the most significant ones, to the exact second (Table 2). For simplification, there exist only two states for all machines: on or off. This situation is the case for all the machines present at the case company. It is possible to extend the model without any restrictions to include machines in partial load operation or with different intensity usage (e.g., speed, revolutions per minute), provided the partial load or different intensities are recorded.

The data can be processed to enable both data sources to be collected in such a way that one data record is created that includes the total energy consumption and the running times of each machine for precisely every 15 min. Being a high energy consumer (above 100,000 kWh per year) the case company is bound by law to collect these data in 15-min intervals (see VDE 2011; VDE 2015 for details). This so-called registration period ("Registrierperiode") is necessary because energy providers must be informed in advance about high energy consumption to avoid capacity overloads. Table 3 illustrates this collective data record in a table.

The collective data represent a system of equations that could be mathematically solved provided there are no errors whatsoever when collecting the data. However, since running times for the machines are often not available for all energy consumers (examples being the lighting, air condition/ventilation in the manufacturing hall) or the data that has been recorded includes inaccurate measurements, the collective data can be quasi-represented by a system of equations with noise. However, this system of equations can generally be estimated using multivariate statistical processes, specifically multivariate regression analysis, whereby the range covered by the data (there would be some 35,000 quarter-hourly load profiles per year for a company with round-the-clock production) would enable a larger number of machines in operation to be estimated. Based on these considerations we specify the following model:

$$Energy_t = \beta_0 + \beta_1 RunTime_{1t} + \beta_2 RunTime_{2t} + \cdots + \beta_N RunTime_{Nt} + \varepsilon_t$$

$$\text{with } \varepsilon_t \overset{i.i.d}{\sim} N(0, \sigma_\varepsilon^2) \quad (1)$$

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Table 3 Collective sample data on the total energy consumption in 15-min units and the corresponding running times of the machines

Date	Starting time	End time	Energy consumption (in kw)	Machine 1	…	Machine 4	…	Machine 10
1/1/2016	0:00:00	0:15:00	1017	0:12:37	…	0:15:00	…	0:04:06
1/1/2016	0:15:00	0:30:00	2053	0:03:47	…	0:15:00	…	0:00:00
1/1/2016	0:30:00	0:45:00	1879	0:11:48	…	0:15:00	…	0:00:00
1/1/2016	0:45:00	1:00:00	878	0:15:00	…	0:15:00	…	0:00:00

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$Energy_t$ is the energy consumption in 15-min units at period t. $RunTime_{it}$ is the running time in minutes of machine i at period t for all machines $i = 1, 2,\ldots, N$ and all periods $t = 1, \ldots, T$. $\beta_0, \ldots, \beta_N$ are the parameters to be estimated, while ε_t is the error term which is independent and identically normal distributed. As mentioned above, this basic model could be augmented by variables that for example capture the intensity (e.g., speed) with which the machines are used—given that this intensity is measured. Naturally, such a measurement of intensity is relevant since it influences the energy consumption of the machines. However, for the examined company this was not the case since the machines could only be run in two states (on or off).

Table 4 depicts the results of the regression analysis described above. 42 machines are included in the calculation. The data is based on corresponding information collected over a period of one year from the case company in the printing industry.

The coefficient of determination R^2 is 0.918. This high value shows that the model gives a good explanation of the differences in the energy consumption of the machines. It further indicates that the noise which is introduced by potential other energy consumption sources (e.g., the lighting in the production facilities) is not substantial. Of the 42 coefficients, 36 show highly significant values ($p < 0.01$), while one of the coefficients is significant at the 5%-level. The estimated values are insignificant for five coefficients. These estimated coefficients each show the energy consumption in kilowatt, if one machine runs 1 min. As expected, all of the significant coefficients show a positive value. For the fair assessment of the regression results and the included machines, respectively, firms must consider the production set-up, i.e., the technical similarity of the machines and the similarity of their outputs. We interpret the first three coefficients as an example. All three coefficients refer to machines that are technically identical and have an identical production output. However, the estimated coefficients show a range of values between 14.087 and 15.669 kilowatt consumption if one machine runs 1 min. For reasons of energy efficiency, it would therefore make sense to use machine 680 first, then machine 681 and, only when the first two production facilities are in full use, machine 684, because machine 680, for example, uses some 10% less energy than machine 684 for the same output.

The results of our analysis changed the behaviour of the case company as follows. First, the case company considered the outcome of the statistical analysis for future production planning, i.e., they included the information concerning the different energy-efficiency of machines by assigning priorities which machines should be used first for production. Second, the case company acknowledged that the statistical analysis is a very fast, easy, and cost-efficient approach to measure energy consumption which in turn makes it easier for them to better include energy efficiency considerations in their cost accounting systems (i.e., for cost allocation considerations). Specifically, the case company estimated that it would have to spend a six-digit Euro amount for the submeters and all the installation and maintenance costs associated with them. This amount is significant for a SME. The management of the company revealed that they appreciated the statistical measurement approach for example because they had in mind how much money they save by avoiding the installation of a submeter system.

Concerning the robustness of the estimation results the narrow ranges for the 90% confidence intervals show that it is possible to accurately estimate the energy consumption for most machines. Further, we can exclude multicollinearity issues for several

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Table 4 Results of the regression analysis of energy consumption for 42 machines

	Coeff.	90% CI	
Machine 684	15.669**	15.323	16.015
Machine 681	14.542**	14.174	14.909
Machine 680	14.087**	13.76	14.415
Machine 675	9.824**	9.454	10.194
Machine 671	9.791**	9.436	10.147
Machine 670	9.426**	9.113	9.740
Machine 666	8.681**	8.359	9.003
Machine 664	8.107**	7.770	8.445
Machine 662	7.394**	6.955	7.834
Machine 660	7.310**	6.708	7.911
Machine 650	7.104**	6.741	7.467
Machine 643	6.852**	6.481	7.224
Machine 642	6.589**	6.032	7.145
Machine 641	6.488**	6.160	6.816
Machine 640	6.200**	5.869	6.531
Machine 636	5.868**	5.531	6.204
Machine 635	5.751**	5.418	6.085
Machine 629	5.318**	4.981	5.655
Machine 626	3.581**	3.245	3.916
Machine 625	3.429**	3.111	3.747
Machine 624	3.140**	2.840	3.439
Machine 623	2.666**	2.281	3.050
Machine 620	2.538**	2.232	2.843
Machine 616	2.409**	2.076	2.742
Machine 615	2.256**	1.894	2.617
Machine 590	2.138**	1.783	2.494
Machine 585	2.124**	1.761	2.487
Machine 579	2.001**	1.691	2.311
Machine 578	1.977**	1.609	2.346
Machine 577	1.668**	1.275	2.061
Machine 576	1.535**	1.191	1.880
Machine 575	1.213**	0.884	1.542
Machine 572	1.213**	0.816	1.611
Machine 571	1.123**	0.724	1.522
Machine 570	1.009**	0.665	1.354
Machine 556	0.838**	0.507	1.169
Machine 555	0.738*	0.153	1.323
Machine 552	0.160	−0.212	0.533
Machine 370	−0.090	−0.467	0.287

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Table 4 continued

Machine 352	−0.566	−1.710	0.577
Machine 351	−0.769	−4.626	3.087
Machine 350	−8.434	−30.046	13.179

N: 35,181; R^2: 0.918; $* p < 0.05$; $** p < 0.01$

reasons. First, almost all coefficients show a significance level of $p < 0.01$. Multicollinearity would produce large standard errors in the related independent variables (Greene 2012, p. 129) which is obviously not the case here. In addition, the highest variance inflation factor (VIF) that we observe is 2.492 which is far below the usual thresholds of 5 and 10, respectively (Menard 1995, p. 66; Neter et al. 1989, p. 409). The absence of multicollinearity issues in this case means that the variance between the single running times of the machines is obviously large enough to separately estimate the coefficients. A further potential robustness check could be to compare the regression results with the energy label given by the manufacturer of the machines. However, the case company stated that the energy consumption labels given by the manufacturer of the machines represent just only theoretical values which have no real informative value in practice. The management of the case company compared energy labels to published fuel consumption profiles of cars. These fuel consumption profiles are derived in a laboratory setting and just provide information about the lowest possible energy consumption profile which, however, can never be realized in a real-life setting. In addition, most of the machines of the case company are in-house developments for which theoretical energy ratings are simply not available.

To sum up, regression analysis based on existing data in the firm can be used to estimate energy consumption in a very simple manner. Physical measurement of the energy consumption of each production unit (e.g., by submetering), which may result in high investment and operating costs, is not necessary. The company thus obtains a basis for optimizing its production and cost allocation that takes energy-efficient aspects into consideration.

4 Implications for environmental management accounting

Environmental management accounting generates, analyses, and utilizes financial as well as non-financial information (e.g., physical information on the use of energy) to support management activities in order to improve the economic and environmental performance of firms and to achieve a sustainable business (Burritt and Schaltegger 2010; Ferreira et al. 2010; Henri and Journeault 2010). There exist several ways to integrate environmental issues into management accounting and management control systems, e.g., by developing specific performance indicators, frequently using these indicators to support decision making, and fixing specific objectives in budgets for environmental expenses (Guenther et al. 2016; Henri and Journeault 2010). As such, it is highly crucial for the successful implementation of an environmental management accounting to develop reasonable methods for measuring energy consumption. Thus, the presented measurement approach is a fast, convenient, and cost-effective tool which may facilitate the use of some important environmental management accounting

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instruments and provide relevant input to fundamental management control systems (see for an overview of such instruments and systems for example (Bouten and Hoozée 2013) and for a detailed review of the empirical literature in this context (Guenther et al. 2016)). Specifically, the suggested approach may contribute to the following environmental management accounting tools and elements of environmental management control systems:

- *Cost accounting:* In the first step of each cost accounting system, the usage of the production factors has to be measured. For many production factors except for direct material, simplified approaches are used because a detailed physical measurement is not considered to be efficient. As a result, in traditional cost accounting systems, environmental costs are usually hidden in manufacturing overhead costs which makes it difficult for managers to observe the actual environmental costs related to their activities (Ferreira et al. 2010). Measuring energy consumption in more detail for each machine allows for a better allocation of environmental costs to specific products, for example through activity-based costing (Bouten and Hoozée 2013). The firm in our case study is characterized by the production of large batches of relatively similar output (printing and binding paperbacks). Assessing the energy consumption of each machine in detail during the production process makes it possible to assign energy costs to production output which is superior to applying a general and undifferentiated manufacturing overhead allocation rate.
- *Providing input to external reporting:* In general, cost accounting and management accounting, respectively, serve as a fundamental information provider for external reporting. The increasing demand for more information about sustainability in the financial statements creates a strong need for more and efficient environmental data collection (e.g., Henri and Journeault 2010). Environmental reporting contributes to the creation of a good corporate image. The suggested statistical approach facilitates the measurement and assessment of energy consumption. Thus, using the approach and reporting about a more detailed measurement of energy consumption would demonstrate to the external environment that the achievement of environmental goals is taken seriously.
- *Budgeting:* Similar to an improved cost accounting with regard to environmental aspects a more detailed measurement of energy consumption enhances the budgeting process, especially with regard to the manufacturing overhead budget. Instead of planning a general, unspecified manufacturing overhead budget which includes the indirect costs for energy consumption and which is based on a general predetermined overhead allocation rate, it would be possible to plan a specific budget for energy costs based on the expected production output, i.e., the production budget determines the running times of the machines which in turn can be used—based on the estimated regression model—to predict future energy consumption and thus energy costs. Furthermore, during the budgeting process, detailed targets for expenses for electricity consumption (e.g., kwh per ton) can be set if such a detailed measurement of energy consumption is implemented. By having such a detailed measurement of energy consumption for individual machines deviations can be monitored through short-term (e.g., weekly) variance analyses and meetings with

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foremen (Bouten and Hoozée 2013). As a result, firms are enabled to better control their environmental performance (Henri and Journeault 2010).

- *Performance measurement:* Perego and Hartmann (2009) find that the alignment to environmental strategy is mostly achieved through the increased quantification of environmental performance measures. Thus, the faster and easier measurement of energy consumption by the suggested approach may facilitate the introduction of environmental performance indicators (EPIs) in scorecards that managers must keep in control and that can help to translate environmental concerns into strategy (Bouten and Hoozée 2013; Burritt and Schaltegger 2010; Kaplan and Norton 1996). In addition, the use of EPIs based on this kind of energy consumption measurement can support more environmental-oriented decision making (Guenther et al. 2016; Henri and Journeault 2010). For example, EPIs for energy usage can be used to control costs or to provide information for internal management reports. In short, such fast and easily determined performance measures are crucial to ensure the effective implementation of any kind of environmental strategy.
- *Incentive systems:* Henri and Journeault (2010) suggest to integrate environmental issues into control systems by linking environmental goals and indicators to rewards. Plant managers are reluctant to such an integration of environmental indicators into reward systems as long as an unambiguous measurement is lacking. Thus, implementing convenient and sound ways to measure energy consumption in production plants by avoiding unspecific allocation rules may help to overcome resistance against the integration of environmental criteria into bonus calculations.
- *Capital investment decisions:* The suggested approach may foster that environmental considerations are more frequently considered in future capital investment decision. If a detailed measurement of energy consumption of machines exist, the management has the possibility to better assess which investments in machinery yield sufficient energy savings and thus financial benefits (Bouten and Hoozée 2013).
- *Cost management (i.e., benchmarking):* The suggested approach can be used for different production facilities and foster more detailed internal benchmarking between these different production facilities. Energy guzzlers can be more easily identified and league tables between production sites could be introduced. Ferreira et al. (2010) provide some first empirical evidence that environmental management accounting is correlated with process innovation which usually entails significant changes to internal production processes. In connection with activity-based costing the suggested measurement approach can help firms to better analyze their production units and identify efficient production units compared to less efficient production units which in turn can facilitate process improvements.
- *Increasing awareness for specific aims (e.g., sustainability) in decision making:* Trianni et al. (2016b) emphasize that awareness and behavioral barriers already affect the first steps to improve decision-making processes for an improved energy efficiency management and for establishing environmental management accounting. The statistical approach may be used as an easy and straightforward approach to raise the awareness for a need to improve energy efficiency management. For example, the statistical approach provides the estimation coefficients for each individual machine. These estimation coefficients allow to divide the energy consumers

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into specific hierarchies (e.g., low, middle, high energy-efficient consumers) given they have to produce a similar output. Thus, based on these hierarchies it would be possible to cluster machines into different production cells and to conduct sensitivity analyses how the energy consumption would change due to distinct scenarios which production cells are used. This could be presented to and discussed with the responsible plant managers and influence their decision-making.

5 Conclusion, limitations, and future research

Many different stakeholders (managers, investors, customers, governments, the general public etc.) emphasize the increased importance of sustainability and the need for an improved industrial energy efficiency (Burritt and Schaltegger 2010). Governments have started several incentives to increase energy efficiency, since this is one of the most promising means to reduce CO_2 emissions which are a result of fossil energy usage (Thollander and Ottosson 2010). As a result, the accounting literature has demonstrated a considerable increase in concern over the issues of sustainability and energy efficiency and how to integrate these issues in management accounting tools and management control systems (e.g., Bebbington and Larrinaga 2014; Guenther et al. 2016; Virtanen et al. 2013). However, one of the first steps to improve energy efficiency and to integrate energy efficiency in management accounting is to achieve a detailed and cost-efficient way how to measure the energy consumption. In this context, our study contributes to the environmental management accounting literature by providing a simple, fast, and cost-efficient method as well as an empirical evidence to improve energy consumption measurement.

In addition, research has suggested that a monitoring system using submetering at plant level is one of the major prerequisites for an adequate energy cost allocation and a successful energy management (Thollander and Ottosson 2010). However, research also reveals that it is very seldom installed in manufacturing companies (Rohdin and Thollander 2006; Thollander and Ottosson 2010; Trianni et al. 2016b). We discuss how our statistical approach using existing data may be used as a starting point for further improvements of environmental management accounting procedures. The interest in such an approach and its integration into management accounting and management control systems from a managerial point of view is that greater energy efficiency is of high relevance since it has direct economic benefits such as increased competitiveness and higher productivity (Henri and Journeault 2010; Thollander and Ottosson 2010; Virtanen et al. 2013), which can also be used to create an improved ("greener") image of the firm (Burritt and Schaltegger 2010).

Naturally, applying the statistical approach to measure energy consumption is just a first step to increase the awareness for a better energy efficiency management within firms. If the management wants to direct corporate culture towards fostering sustainable development, energy efficiency measurement has to become an integral part of the performance evaluation (Introna et al. 2014; Trianni et al. 2016b; Virtanen et al. 2013). May et al. (2015) for instance have emphasized in their study that current industrial approaches lack the means and appropriate performance indicators to compare energy-use profiles of machines and processes. Further research may examine how

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statistical approaches could be applied for the consumption of other energy sources (e.g., water) in order to provide energy-related information as input for environmental management accounting in a fast and efficient way.

A limitation of the statistical approach to energy consumption measurement is that a valid energy consumption cannot be estimated using a statistical approach for a small number of machines that run extremely seldom (only a few minutes per year) or that have a very low energy consumption. Furthermore, firms must consider if there are any potential critical production couplings between machines which in turn would result in multicollinearity issues. If that is the case then the machines which are strongly coupled should be included as one group of machine in the regression.

We have considered an example of the printing industry. This industry is a process industry, where goods are typically produced in bulk quantities (Virtanen et al. 2013). It is a "large scale, complex economic processing system, which contains within it distinguishable smaller interacting subsystems, such as processing technologies" (Virtanen et al. 2013, p. 405). Usually, a common utility system services a number of processes. Therefore, the challenges with regard to the measurement and management of energy efficiency are comparable within such kind of process industries. Therefore, the results of our presented approach for the printing industry can be transferred to other process industry sectors (e.g., food, beverage, metallurgy, chemicals etc.). If even energy-intensive industries like our studied printing plant do not focus on a more efficient energy measurement and management it is likely that it is even less emphasized in less energy-intensive industries. This observation leads to the conclusion that there exists a large untapped potential concerning much cleaner and more environmentally friendly operations in a broad range of different industrial sectors. As a consequence, future research may examine other industries and how existing data in these industries may be used in order to foster information input for environmental management accounting.

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