What effects does material flow cost accounting have for companies? Evidence from a case studies analysis

Matthias Walz¹ | Edeltraud Guenther²

¹ Technische Universität Dresden, Environmental Management and Accounting, Dresden, Germany
² Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES), United Nations University, Dresden, Germany

Correspondence
Edeltraud Guenther, Technische Universität Dresden, Sustainability Management and Environmental Accounting, Münchner Platz 1/3, Dresden 01062, Germany. Email: ema@mailbox.tu-dresden.de

Abstract
Material Flow Cost Accounting (MFCA) is a new cost accounting method which enables the identification of improvement opportunities in terms of material consumption and accrual of costs. Until now, no meta-analysis concerning MFCA has been undertaken. 73 case studies about MFCA use in companies have been analyzed and synthesized in order to determine the effects and drawbacks experienced by these companies when implementing and applying MFCA. The focus of the case studies was MFCA, although, the reported effects cover a broad spectrum. By comparing and synthesizing over 700 statements in the case studies, a clear picture of the experiences reported by companies after having applied MFCA is presented. Whilst the majority of the case studies describe positive effects of MFCA, the reader must consider the described effects with caution, as the insights provided are the best that can be achieved given the limited availability of data. This research may be helpful in practice when considering whether to use MFCA, and in theory as a basis for further research due to its rich description of aspects of the application of MFCA in practice.

KEYWORDS
environmental cost accounting, environmental management accounting (EMA), environmental management control systems (EMCS), industrial ecology, material flow analysis (MFA), material flow cost accounting (MFCA)

1 | INTRODUCTION

Despite the idea of industrial ecology is well established in academia (Cohen & Howard, 2006; Ehrenfeld, 2004), the same cannot be said for in actual business practices (Hoffman, Corbett, Joglekar, & Wells, 2014). In order to analyze the reasons behind this gap, a research stream must examine the barriers to transferring industrial ecology into daily practice (Davis, Nikolic, & Dijkema, 2010; de Haes, Heijungs, Suh, & Huppes, 2004; Grant, Seager, Massard, & Nies, 2010; Huppes & Ishikawa, 2011). As industrial ecology focuses on physical data and strives for zero waste concepts, the financial costs of such concepts are currently only considered in cost–benefit analyses and life cycle costing (Klöpffer & Ciroth, 2011; Norris, 2001). However, this is still not enough to spur the attention of business managers. Hoffman et al. (2014) perceived a gap between the business perspective and the industrial ecology perspective. They speculate about the lack of attention to business issues in the industrial ecology field in
general, as well as a lack of attention to industrial ecology issues in the business management field and see a considerable need to fill the void at the interface of business management and industrial ecology. Several authors state that industrial ecology has the perspective to attract a manager’s strategic thinking toward a green conduct of business, due to the potential for industrial ecology to foster strategic benefits (Erkman, 1997; Esty & Porter, 1998). Kokubu (2003) argues that there have been debates over the effectiveness of life cycle assessment, and demands a connection between the environmental conservation system and the corporate management system for economic activities. Cost accounting and, beyond that, cost management have the potential to fill the void at the interface of business management and industrial ecology, by changing the thinking of a business manager through the application of a new accounting method (Fleischman & Tyson, 1998; Hoskyn & Mace, 1994).

The role of cost accounting in industrial ecology is, to date, rarely addressed in the literature, with only a few contributions in existence (Berry & Rondinelli, 1998; Ehrenfeld & Gerlert, 1997; Guenther, Hoppe, & Endrikat, 2011; Heiskanen, 2002; Oldenburg & Geiser, 1997; Schmidt, 2015; Schmidt & Nakajima, 2013; Van Berkel, Willems, & Lafleur, 1997). Cost accounting information can spur the attention of industrial ecology engineers toward business issues, so that they can present industrial ecological solutions in terms of technical benefits and cost benefits. Furthermore, the combination of cost accounting and physical quantities can attract the attention of business managers toward environmental issues. At the United Nations Conference on Sustainable Development in Rio in 2012, Peter Bakker boldly claimed that “if we could just change accounting practices, we could save the world” (Bakker, 2013). Accounting scholars state that “the journey forward in sustainable development will almost certainly demand changes in the practice of management accounting” (Contrafatto & Burns, 2013, p. 365).

Case studies on the new accounting technique, Material Flow Cost Accounting (MFCA), were analyzed to see what effects can be seen in practical usage, due to its specific development for the intention of connecting corporate management and management control with the environmental department and production management (Wagner, 2015). This was the actual advent of MFCA and its predecessors: Scientists compiled detailed input/output tables of all substances for whole factories, however, due to a lack of monetary information, management was not receptive (Wagner, 2003, 2015). Other environmental management accounting tools (Burritt, Hahn, & Schaltegger, 2002) either do not, or only partly contribute to closing the gap between industrial ecology and business management. However, MFCA does provide financial analyses for management, which has an impact on the environmental performance of the company. This paper aims to provide to academics and practitioners—for the first time—a broad and detailed overview of the effects of MFCA experienced in practice by synthesizing the experience gained in 73 case studies. For example, while 60% of the case studies do not describe a financial effect of MFCA at all, this analysis generates 36 financial effects and describes them with illustrative quotes. However, the reader should note that these insights are based on a limited availability of data. Therefore, the described effects are tentative until such a time there is more data available. The rest of the article is structured as follows: after briefly explaining the basics of MFCA, the next section describes methodological issues concerning the case studies’ review, while drawing on content analysis (Krippendorff, 2012) and methods for the synthesis of qualitative research in general (Miles & Huberman, 1994). Subsequently, we present the results before discussing the findings and draw some conclusions.

## 2 | MATERIAL FLOW COST ACCOUNTING

MFCA is a new accounting and assessment method which combines monetary and physical data. MFCA quantifies energy, material consumption, and waste output in physical and monetary units (Guenther, Rieckhof, Walz, & Schrack, 2011). The uniqueness of MFCA lies in the allocation of all production costs either to the intended output (the product), or the unintended output (all waste occurring over all the production steps). Thereby, the transparency of material flows and the associated costs increases considerably; inefficiencies concerning material and energy consumption are revealed, and hidden costs uncovered. In the example in Figure 1, the costs are allocated according to weight (with the exception of waste management costs), showing that 66.5% of the costs do indeed add value to the product. The conclusion from an MFCA analysis presents the question as to how this ratio could be improved. The MFCA analysis could be refined by splitting the non-product output into technically necessary waste and avoidable waste in order to identify rather simple measures for waste reduction that could be implemented; the technically more complex processes could be tackled afterward. The goal is a theoretical value of zero non-product output, while keeping economic boundaries in mind. One strength of the MFCA method is the integrated plan-do-check-act (PDCA) cycle. After planning and implementing MFCA, the people responsible for the single production process should start with the analysis of the data (check) and develop the necessary actions to improve the process (act). Some changes in the process can be made without much coordination; here, the improvement measures are executed directly after the MFCA analysis. However, most production processes are already optimized; changing a running system is complex, and plant managers are rather reluctant to make changes for what are often only minor improvements. Thus, one weakness of the MFCA method is its application in complex production processes because here, the MFCA analysis may not always be followed by the execution of measures for improvement.

Arguably, the application of MFCA is notably beneficial for companies, because costs and wastes could be simultaneously reduced (Christ & Burritt, 2015; Nakajima, 2006; Onishi, Kokubu, & Nakajima, 2008; Schmidt, 2015; Wagner, 2003). The focus of this study (Mintzberg, 1979), is to find out if, and what kind of evidence exists for the effects of the application of MFCA in companies. It is evident the use of MFCA can be beneficial, as is shown in a number of cases studies. An international MFCA community has emerged over the last 20 years, consisting of academics, practitioners,
and governmental bodies that have formulated a standard procedure on how to proceed when carrying out MFCA in DIN-EN-ISO 14051 and DIN-EN-ISO 14052 (ISO, 2011, 2017). MFCA is seen as a tool for increasing resource efficiency and thus contributing to the sustainable development goals (SDG) of the United Nations (2015), and is a major tool in the SwitchMed project framework of UNIDO (SCP/RAC 2015). However, there are still conflicts with existing management perspectives (Kokubu & Kitada, 2015) when using MFCA. While evidence is given in single case studies, it is not yet clear if this is an individual phenomenon, or if MFCA is beneficial in general. Additionally, we do not know if there are similarities or differences in the objectives of the authors, and in the results of the MFCA case studies. Moreover, we do not know the potential of MFCA as a tool for the strategy of a company, or for industrial ecology.

73 MFCA case studies were analyzed to identify the effects experienced by companies after the application of this new accounting tool. To that end, we have chosen an approach that comprises three steps: first, we wanted to find motivations for applying MFCA—when considering MFCA, what do companies expect from the application of the tool? Second, the companies detailed their experiences of the implementation MFCA, and third, we looked at the outcomes of MFCA concerning financial, environmental, and strategic aspects—which mainly cover the interests of business management. As part of this step, we also considered the actions triggered by MFCA.

3 | RESEARCH APPROACH AND METHODOLOGICAL ISSUES

The research process was structured as is depicted in Figure 2.
in understanding the social systems. This solidified our research approach of analyzing and synthesizing all available MFCA case studies both to accumulate knowledge from a range of case studies, and to better understand the MFCA phenomenon. Moreover, we expected to identify general patterns concerning rationales for using MFCA, success factors and obstacles when using MFCA, effects from using MFCA, and actions resulting from MFCA use.

Thus, our research question is:

“What effects of the application of MFCA did companies experience in practice?”

This research question has various implications for the research methodology, as it requires empirical data from companies which actually apply MFCA in their organization. In principle, data could be gathered by direct research within the companies, or by secondary research in the existing literature (Hunt, 1997; Hunter, Schmidt, & Jackson, 1982). Carrying out a review of the literature to gather evidence about the current research state in a specific discipline is a key research objective (Tranfield et al., 2003). Zumsteg, Cooper, and Noon (2012) offer a checklist for systematically reviewing life cycle assessment data in order to conduct and report systematic reviews. We adapted parts of their approach to MFCA case studies. In order to get an overview about the relevant literature, we searched in important scientific databases: Sciencedirect, Emeraldinsight, Link.springer, Onlinelibrary.wiley, Web.ebscohost and Web of knowledge, Google Scholar, as well as the internet search engine Google. We did not restrict the search to certain sources because in this first step we wanted to identify as many case studies, reports, and even hints at the application of MFCA in a company. The reason for this broad approach, which ventures beyond the conventional focus on refereed journal articles, was the fact that while MFCA drew attention early on in business practice, this was not the case in academia. The search term “material flow cost accounting” generated 287 hits on November 15, 2013, in Google Scholar. Those hits, and the hits in the other databases, were examined as to whether they encompassed an MFCA case study. We updated this search in 2016 and, as a result, we found 73 companies where—according to the sources—MFCA is applied. Further progress was made on October 12, 2018, with 926 hits on Google Scholar for the search term “material flow cost accounting”; resulting in 21 additional case studies which are described separately (see Appendix 2 in Supporting Information S5). When the name of the company was given, we searched for further sources for this specific case, using the search term ("Company Name" AND ("material flow cost accounting" OR MFCA)). When the company name was not given, we searched for further sources on the specific case using the search term ("Author Name" AND ("material flow cost accounting" OR MFCA)). At this stage, we applied two exclusion criteria for sources: first, the sources should meet certain publication standards (i.e., professional, trade, and industry journals), in order to consider the information to be reliable. Second, the information contained in a source should do more than simply describe the fact that the company in question has applied MFCA.

3.1 | Review of methods for data analysis of case studies

After the search methods described above, we decided to move ahead with the subsequent results as the basis for our study, and not to conduct primary research. We included the case studies identified in the 2016 research update. The update in October 2018 was used to check if the results of the analysis using cases identified up until 2016 would come to other conclusions. With the description of the application of MFCA across 73 companies comprising a total of 371 pages, we assumed the data would be enough to answer the research question by conducting a synthesis of the findings described in the identified sources. A research synthesis can include the summarization, integration, and cumulation of the findings of different sources (Glass, 1977; Mulrow, 1994). The secondary analysis of multiple studies has a long tradition across various academic disciplines (Newig & Fritsch, 2009); the application of methodological rigor to reviews is no less important than as for primary research (Cooper, 1982). Even so, the task of condensing 371 pages into 3–5 pages represented a huge challenge—to us, it was the equivalent of reducing an entire speech into a sentence. Therefore, we reviewed case study analysis methods in several scientific disciplines and drew on the procedures described below for our analysis.

3.2 | Research synthesis methods

We followed the scientific guidelines for conducting integrative research reviews formulated by Cooper (1982), where he describes potential threats to validity and how validity can be protected during the five stages of the review process: from problem formulation, to data collection, evaluation of data points, data analysis, and up to the presentation of results.

In order to identify the type of analysis method which would best fit to our research question and our sources of data, we examined research synthesis methods proposed in the literature (Zhao, 1991) (see Supporting Information S1 for an overview). We specifically looked for methods dealing with the synthesis of qualitative research in general (Miles & Huberman, 1994), and for the synthesis of case studies. In order to better judge and code a single case study, we also examined relevant literature for examples (Huff, 1999) of how to conduct and evaluate a case study and how to conduct a study of case studies (see Supporting Information S2). As the sources dealing with MFCA applications in practice are mainly reports and case studies, we paid particular attention to the literature which described methods for how case studies can be synthesized (see Supporting Information S2 and S3). To complete the picture of case study analysis, we also examined the literature regarding the identification of cri-
teria for our purpose assessing the quality of a single case requiring investigations (see Supporting Information S4). After considering the given recommendations, we drafted a research method; taking into account the heterogeneity in terms of length, depth, focus, structure, and style of MFCA case studies conducted so far.

### 3.3 Research method

Following our literature analysis, we conclude that there exists a rich and varied body of methods, frameworks, and guidelines for the undertaking of a research synthesis of qualitative case studies—all of which aim to apply rigor, and to achieve scientifically tenable results. We drew upon the ideas and concepts of the presented literature, with the particular utilization of the following: the research guidelines and standards proposed by Cooper (1982) on reviews of research, by Mayring (2003) on the development of coding schemes, by Yin (2014) on elements of a case study, by Bullock (1986) on conducting a case meta-analysis and on coding text, by Bullock (1986) and Jensen and Allen (1996) on inclusion, exclusion, and splitting criteria, by Cepeda and Martin (2005) on the understanding of original studies, by Jensen and Allen (1996) and Thomas and Harden (2008) on the summarizing of findings and of qualitative data, and by Walsham (1995) on the generalization of the results. References to the guidelines and standards we incorporated can be found in the paragraphs below. Details on the research guidelines and standards drawn upon are depicted in Supporting Information S1–S4. Our results determined our method of proceeding: To start with, we found that the identified MFCA case studies rarely met the criteria of good case study research described in the examined literature. For example, only 10% of the case studies provided information about the sources of their data, as recommended by Yin (2014). To combat this, we developed further specific criteria in order to judge the quality of the MFCA case studies based on the DIN-EN-ISO 14051 standard for MFCA. Criteria included the extent to which MFCA issues and procedures were described in a case study in reference to the implementation, modules, results, improvement measures, and success factors/obstacles of MFCA application.

#### 3.3.1 Coding scheme and coding

The "data" of a meta-synthesis are the original insights that the researchers of the primary studies have generated (Hoon, 2013). To categorize evidence from MFCA case studies, the case studies were analyzed according to a comprehensive list of codes. We followed Mayring’s (2003) approach to develop a coding scheme: deductive category application and inductive category development. We included all relevant aspects of MFCA by translating the requirements of MFCA as defined in standard DIN-EN-ISO 14051 into codes. In DIN-EN-ISO 14051, a PDCA cycle is suggested when applying MFCA. The steps and elements in the PDCA cycle were used as codes (see the table in Appendix 3 in Supporting Information S5). Analyzing according to the categories derived from DIN-EN-ISO 14051 will allow for a comparison of the theoretical concept of MFCA with its actual use. In addition, we coded general data on the company described in the case study, and meta-data about author, document, reporting method, participants of the study, duration of study, purpose of the study, compositional structure of the study, rationale to conduct the study, sources of evidence, and information about the sources of evidence (Yin, 2014). Furthermore, for each article the coders provided a brief statement on their overall thoughts regarding the specific article in terms of quality, depth, and usability for further analysis. After testing the initial coding scheme with seven heterogeneous case studies, we refined and amended the coding scheme accordingly (Bullock, 1986). For example, for some cases we added a new coding category when the given codes were too specific and did not cover the statement in the text. All codes were agreed upon by the authors and were described in a short memo. Coding the case studies was a quite mechanical task, which saw us code every text passage (word by word) to fit to a certain code. It was sometimes the case that one text passage was coded with different codes. We also coded textual and graphical content. In total we created over 2,800 codings in 73 case studies with the help of MAXQDA software.

#### 3.3.2 Inclusion, exclusion, and splitting criteria

As Bullock (1986) and Jensen and Allen (1996) recommend, we set the inclusion criteria broadly in order to get a comprehensive picture of MFCA use in companies. However, case descriptions were excluded when they did not specifically apply MFCA as described in DIN-EN-ISO 14051. Case descriptions that were described in an abstract or in a short summary but had not been published or made available from the author (either for confidentiality reasons or other reasons) were not included in the sample. When the same organization had already been covered in another paper, the case itself was not included as a new case, but information from these articles was included in the case analysis of this particular organization. As there are different sources for the case studies, it follows that there are different qualities. For example, nearly half the cases come from a single government source (32 out of 73 are from the Ministry of Economy, Trade and Industry of Japan [METI], 2011). Therefore, we generated two subsamples out of the full sample. The full sample comprises 73 cases from a range of refereed and unrefereed sources. The first subsample, which consists of 36 cases ("subsample 1"), eliminates all cases that stem from non-academic sources. The second sample of 18 cases ("subsample 2"),
considers only sources from academic journals or book chapters, but not unrefereed conference papers. To summarize, we applied a broad filter for including MFCA case studies. We analyzed the case studies from the point of view of an interpretivist (Cepeda & Martin, 2005), which means that our understanding is built on the subjective understanding of the author of the case study.

### 3.3.3 Synthesizing data

In order to summarize and synthesize data, we followed a cascade procedure where we first summarized the codings through short citations, or with our own wordings. Following this, we built categories of statements under which the summarized codings (or parts of them) could be subsumed. In this aspect, we followed Jensen and Allen (1996) and Thomas and Harden (2008) by comparing and contrasting, and also translating the codings into one another and synthesizing these translations. We then counted the occurrences of statements consolidated in a specific category. These categories and the number of occurrences are presented in the results section for the purpose of providing a rich insight (Walsham, 1995).

### 3.4 Limitations of the analysis of the MFCA case studies

We present the limitations of our study ahead of our presentation and discussion of the results because this helps the reader to better judge the results and observations while reading the next sections. The limitations of this analysis of MFCA case studies are complex and amplified, due to the analysis building upon single case studies that in themselves, have individual limitations. On the level of the single case studies and on the level of the case studies analysis, limitations stem from the choice of methodologies used by the researchers of the original case studies, and from restrictions inherent in the research object (e.g., the case company or the single case study).

Limitations of this study must be considered due to various reasons. First, the analysis is confined to published case studies; perhaps more experiences in relation to the application of MFCA exist, but have not been published, and therefore cannot be included in the sample, the results of which could have been altered. In addition, there might be bias concerning the fact that case studies with positive results may be more likely to have been published. However, we generally assume that academics would have published their results regardless of whether the results of the application of MFCA were positive or negative—especially if the purpose of the study was to describe or to examine the MFCA method, which is true in 27 (87%) of the 31 cases (5 studies did not give a reason) in subsample 1 (36 cases). Second, published case studies might be biased in so far as only positive aspects of MFCA were reported and negative aspects neglected; either because the companies did not report all aspects of the application of MFCA or the authors of the case studies did not realize or report all aspects. Third, the literature on MFCA may not be sufficiently mature enough to draw conclusions; for example, no study exists where MFCA is evaluated as a useless or impractical tool. Fourth, the survey includes in the full sample multiple non-refereed publications. This was controlled by splitting the full sample into two subsamples that contain only academic sources (subsample 1), or only refereed sources (subsample 2). Fifth, the single case studies vary considerably in terms of quality according to the criteria for good case research suggested by Plekkari, Plakoyiannaki, and Welch (2010) and Yin (2014); for example, only 3 cases (out of 37 = 8%) of the non-academic case studies describe their sources of evidence in comparison to 10 cases (out of 18 = 56%) in academic refereed articles. Sixth, the possibility exists that the authors of the paper have interpreted the statements in the case studies incorrectly, even though two coders coded the case studies. Seventh, relevant aspects may not have been analyzed either by the authors of the original case studies, or by the coders due to an inadequate or incomplete coding scheme. Eighth, due to time restriction, the analysis does not include the most recent MFCA case studies. Although all recent MFCA studies (listed in Appendix 2 in Supporting Information S5) were screened by the authors, single results could have changed slightly. In addition, we would like the reader to keep in mind that the absence of a statement in a case study concerning a specific topic does not necessarily mean that this particular topic has had no effect in this case study. It instead means that, for various reasons, the examined topic was simply not covered by the study. Such reasons include, but are not limited to, the following: confidentiality, unintended omission, different focus of the study, results being unavailable or not available at the time the study was written, or that while companies really do achieve large cost savings through MFCA, they do not want to publish such results because this could increase the unwanted pressure from customers to lower prices. As previously stated, the reader should note that these insights are based on a limited availability of data. Therefore, the described effects are tentative until such a time that more data is available.

### 4 RESULTS AND DISCUSSION OF A META-SYNTHESIS OF MFCA CASE STUDIES

In this section, we present the results of the meta-synthesis of the MFCA case studies and search for possible explanations. The meta-synthesis demonstrated our understanding of the application of MFCA based on the individual MFCA case studies—and is not to be confused with an evaluation of the accounting method MFCA. Management accounting systems should provide information to enable efforts to control costs, to measure and improve productivity, and to devise improved production processes (Johnson & Kaplan, 1987). This also applies to MFCA; there is a difference between the provision of information by MFCA, and the impact of that information on a company’s change of actions. MFCA has a special...
characteristic, however, because this management accounting technique also represents a method for problem-finding (Nakajima, 2020). Moreover, it should be noted that it was not always clear in the case studies examined as to whether the efforts and effects described resulted from the use of MFCA only, or whether there were other explanations for the effects at the same time.

We expected that the case studies which examined the use of the same management tool (use of MFCA) would be similar in approach and focus. However, the analyzed case studies varied considerably in approach and focus despite all encompassing the use of the same management tool (MFCA). The boundary and industry of the case companies were separately coded and differed significantly. More often than not, a production process was chosen as a system boundary for the application of MFCA. Due to the heterogeneity of the descriptions of the case studies, it would be difficult to make a general statement such as “textile companies benefit more from the application of MFCA than metal processing companies.” Moreover, the cases were published in both academic and non-academic sources. We have aimed to show the rationales for using MFCA, success factors, obstacles, and effects when using MFCA, and actions resulting from MFCA—which could be generalized, although individual case studies may cover very fragmented topics. Interestingly, while the number of environmentally related cases (where environmental rationales were given) was equal to, or higher than, the number of cases where environmental effects were presented (11 in subsample 1; 6 in subsample 2), the opposite was true in the financial area—with the number of cases with financial rationales having lower than the number of cases (15 in subsample 1/8 in subsample 2) where financial effects were reported. Thus, although this was not the purpose of the study, in some cases, financial effects were reported.

Of the 73 MFCA case studies analyzed, not a single case description, nor the method of MFCA itself, nor its application, has been characterized as insufficient. The vast majority described positive aspects of using MFCA, including increases in the process transparency, provision of better foundations for calculation, and eventual cost reductions and improvement measurements. The systematic approach of MFCA toward waste reduction in contrast to ad hoc activities is described as one of the particular strengths of the method. One challenge that companies described in regard to the application of MFCA was the often cumbersome task of generating the raw data—such as material balances, material flows, and their related costs—but doing so led to effects (as shown below) which would have otherwise remained unrealized. We examined the case studies by describing the various occurrences, which encompassed a wide range of circumstances, and not merely the quantitative distribution. The analyzed case studies are listed in Appendix 1 in Supporting Information S5. When reference is made to the analyzed case studies, the number of the table row in the list is given in square brackets (see the table in Appendix 1 in Supporting Information S5).

4.1 Rationale for MFCA

The actors who expressed plans to implement MFCA in their companies have certain expectations of this new accounting method. It was noted that in 34 (47%) of the 73 cases of the full sample, 17 (47%) of the 36 cases of subsample 1 (academic sources only), and 8 (44%) of the 18 cases of subsample 2 (refereed sources only), 1 reasons were provided as to why the companies chose to deploy MFCA. The motives reported are diverse; on average, two different reasons were given per case study. The companies deployed MFCA due to economic, environmental, or organizational reasons (77 occurrences in the full sample, 41 and 20 in subsamples 1 and 2, respectively; in some case studies, two or more reasons from the same category were given). Omron Relay & Devices Corporation (Japan) (METI, 2011e) explicitly states the following reasons for applying MFCA: “To achieve a 10% reduction in material loss in the processes of pressing, heat treatment, and plating,” and “[t]o achieve a win–win relationship after introduction of MFCA through continuous effort, such as application of the subject process to the manufacturing of other components.” The analysis of the case studies provides a broad range of reasons for the initial commitment of companies to MFCA. The main reasons and specific reasons for choosing MFCA are depicted in Table 1.

The results above show that MFCA is appropriate for various tasks and could be a foundation upon which further investigations concerning waste and costs could be based.

4.2 Success factors and obstacles

Before MFCA is applied on a constant basis, it must be successfully introduced into an organization. In total, 15/14/5 cases out of 73/36/18 (21%/39%/28%) listed success factors for the implementation of MFCA. Also mentioned were the following success factors: management support, including MFCA in an enterprise resource planning (ERP) system, internal communication about MFCA, multi-unit and multi-level team composition, a demonstration of the monetary effect due to MFCA, performance evaluation due to MFCA, recognition of the usefulness of MFCA, and collaborations with suppliers. Success factors for a constant application of MFCA were named in 7/4/3 case descriptions out of 73/36/18, and include the following: a demonstration of the benefits of MFCA, execution of improvement discoveries, to show value of loss, to involve the right people, the integration of MFCA in management control system (MCS), the integration of MFCA in target settings, the integration of MFCA in innovation processes, and the low effort requirements of MFCA. 13/10/6 out of 73/36/18 (18%/28%/33%) mention a particular obstacle faced during the implementation of MFCA—namely the difficulties experienced when gathering the data physically, or when installing an interface to the existing accounting system. Others reported the following obstacles: knowledge regarding the process is required, collaboration with suppliers is
### TABLE 1 Main reasons and specific reasons for choosing MFCA

| Sub-category: Main reasons                                                                 | Number of studies/occurrences | Illustrative quotes                                                                 |
|--------------------------------------------------------------------------------------------|------------------------------|-------------------------------------------------------------------------------------|
| **Economic reasons (such as reduction of costs or identification of hidden costs)**         | Full sample (73 cases)       |                                                                                     |
| Subsample 1 (36 cases)                                                                     | Subsample 2 (18 cases)       |                                                                                     |
| Economic reasons (such as reduction of costs or identification of hidden costs)            | 37 (51%)                     | “Alpha was keen to transform these into cost savings and can see that MFCA has great potential to assist Alpha in doing so.” [71] |
| Organizational reasons (such as using MFCA as a tool to enhance quality or improvement of processes) | 22 (30%) | “The objective of introducing MFCA in the aforementioned two companies was to minimize total material losses in the supply chain by reviewing a layout at the design phase.” [55] |
| Organizational reasons (such as using MFCA as a tool to enhance quality or improvement of processes) | 18 (25%) | “The objective of this project was twofold: To establish an indicator for process improvement and cost reduction, and to connect it with the goals of enhancing quality, resource-saving, and energy-saving.” [35] |
| **Specific reasons**                                                                        |                              |                                                                                     |
| Increase corporate environmental performance                                                | 11 (15%)                     | “The company implemented MFCA as a means for reducing its environmental impact.” [58] |
| Identify sources for improvement                                                            | 8 (11%)                      | “MFCA was used to identify an inefficient process which has high negative product cost.” [23] |
| Reduce losses                                                                               | 8 (11%)                      | “MFCA was initially implemented in processing areas and subsequently introduced to the non-processing workplace to achieve company-wide waste reduction.” [31] |
| Use as a tool                                                                               | 7 (10%)                      | “One Japanese company introduced MFCA as an environmental management tool to overcome operating losses.” [10] |
| Source for decision-making                                                                  | 6 (8%)                       | “…to use the MFCA result as a source for decision-making when making an investment to curtail the identified losses.” [49] |
| Reduce costs                                                                               | 6 (8%)                       | “… MFCA was implemented for process improvement and cost improvement which eliminates waste, and to improve environmental performance by reducing energy costs through the efficient use of resources.” [38] |
| Identify material losses                                                                    | 6 (8%)                       | “To introduce MFCA to the outsourced processing process by the suppliers with the aim of visualizing potential losses (e.g., material loss, energy loss, information transmission loss, and the loss due to rather complex issues arising from the relations between the companies).” [54] |
| Improve a process                                                                           | 5 (7%)                       | “…locating and improving operational weaknesses and, thereby, enhancing financial and environmental performance after establishing MFCA is an important topic for small- and medium-size enterprises.” [01] |
| Increase productivity                                                                       | 4 (5%)                       | “The introduction of MFCA at this project involves an examination of the yield ratio of material, and it aims to achieve further productivity enhancement, cost reduction, and environmentally friendly manufacturing.” [34] |
| Get physical and monetary data about losses                                                 | 3 (4%)                       | “MFCA supports JBC Food in tracking and costing material use and material losses to support material efficiency improvements and the vision of zero waste.” [09] |

(Continues)
### TABLE 1 (Continued)

| Specific reasons                                  | 1 (1%) | 2 (3%) | 3 (4%) |
|---------------------------------------------------|--------|--------|--------|
| Measure costs of non-product output               | 3 (4%) | 3 (8%) | 2 (11%)|
| “...the Material Flow Cost Accounting (MFCA) approach was used to measure the quantity and value of the non-product output costs.” [05] |

| Take flow-oriented perspective                     | 2 (3%) | 2 (6%) | 2 (11%)|
|---------------------------------------------------|--------|--------|--------|
| “...environmental cost accounting at JBC should ideally take a flow-orientated perspective with attention to energy and waste issues. MFCA is a specific environmental cost-accounting approach that meets these requirements.” [09] |

| Underline economic value of physical amounts       | 2 (3%) | 1 (3%) | 0 (0%) |
|---------------------------------------------------|--------|--------|--------|
| “The goal has been to underline the economic value of the physical amounts associated with manufacturing process in order to show the economic value of material losses.” [22] |

| Identify management problems                        | 2 (3%) | 2 (6%) | 0 (0%) |
|---------------------------------------------------|--------|--------|--------|
| “…MFCA was proposed with the initial motive to increase production efficiency and identify management problems.” [67] |

| Discover hidden costs                               | 2 (3%) | 0 (0%) | 0 (0%) |
|---------------------------------------------------|--------|--------|--------|
| “…it was very meaningful to identify hidden cost related not only to materials but also to system and energy.” [26] |

| Establish an indicator                               | 1 (1%) | 0 (0%) | 0 (0%) |
|---------------------------------------------------|--------|--------|--------|
| “The objective of this project was twofold: To establish an indicator for process improvement and cost reduction, and...” [35] |

| Achieve win-win relationship in supply chain         | 1 (1%) | 0 (0%) | 0 (0%) |
|---------------------------------------------------|--------|--------|--------|
| “To achieve a win–win relationship after introduction of MFCA through continuous effort, such as application of the subject process to the manufacturing of other components.” [54] |

Note: The numbers in brackets refer to the citation numbers (the left column) of case studies listed in Appendix 1 in Supporting Information S5.

necessary, the high effort involved in MFCA analysis, or the resistance from employees. 12/10/6 out of 73/36/18 (16%/28%/33%) mentioned some type of obstacle during the application of MFCA; employees balanced the benefits against the effort of MFCA and regarded the level of effort as relatively high. Another impediment for MFCA mentioned in four case studies was the reliability of the data. Furthermore, difficulties involved in defining suitable MFCA parameters, the requirement of specific know-how, and the limited availability of data were mentioned. Dividing the sample into subsamples shows that success factors and obstacles of MFCA are more often described in academic sources. Table 2 lists various success factors and obstacles for the implementation and for a constant application of MFCA.

### 4.3 Effects through MFCA

Following its application, the effects of MFCA should be checked. Identifying inefficiencies through MFCA results in reduced waste and costs and often better working conditions. By synthesizing the 73 case studies, it became clear that MFCA has financial, environmental, strategic, and other effects, although only 23%/25%/22% of the case studies describe more than one effect. Chang, Chiu, Chu, Wang, and Hsieh (2015) state that their case study “has validated that the MFCA is not only a decision-making tool, but also an instrument to assist corporations in undertaking their social responsibilities.” The majority of the case studies in our analysis, however, concentrated on financial and environmental effects. Illustrative quotes taken from the case studies underpin MFCA’s role in contributing to those effects. For some sub-categories, the effects could be classified in multiple sub-categories: for example, describing an effect of MFCA as strategic is often not clear cut; a strategic effect refers to any influence that has a lasting effect on the disposition of an organization (Angell & Smithson, 1991). Such a strategic effect could also have financial and environmental effects, though rather indirectly. The described financial and environmental effects are mostly visible or measurable, or short term.

### 4.3.1 Financial effects of MFCA

30%/36%/39%, or 22/13/7 out of 73/36/18 case studies, explicitly reported a positive financial effect (cost reduction) through the application of MFCA. In no case study is it mentioned that the application of MFCA has had a negative financial effect. Some companies provided absolute figures; for example, Sekisui Chemical Co., Ltd (Japan) (METI, 2011a) reported that costs were reduced by 5.3 billion yen within 2 years (which is, for 2 years, 65 million US dollars, or approximately 0.3% of sales, assuming reduction was equally distributed between the 2 years). The various effects of MFCA
| Sub-category                                      | Number of studies/occurrences | Illustrative quotes                                                                 |
|--------------------------------------------------|-------------------------------|-------------------------------------------------------------------------------------|
|                                                   | Full sample (73 cases)        |                                                                                      |
|                                                   | Subsample 1 (36 cases)        |                                                                                      |
|                                                   | Subsample 2 (18 cases)        |                                                                                      |
| Success factors for the implementation of MFCA  |                               |                                                                                      |
| Thorough preparation of MFCA processes           | 6 (8%)                        | "As it is important for the project staff members to understand MFCA prior to its introduction, a meeting was held to clarify points of implementation." [57] |
| Successful experience due to MFCA               | 6 (8%)                        | "The company’s willingness to account for physical information and improve the measurements required increased as some initial benefits from EMA [MFCA was applied] became apparent." [64] |
| Management support                               | 3 (4%)                        | "The implementation might have failed if we did not have the support of management and the data provided by the accountants." [01] |
| Include into ERP system                          | 2 (3%)                        | "MFCA implementation was difficult in its calculation at the introduction phase. In order to overcome this issue, we introduced a system using the mission-critical enterprise system called “SAP R/3”." [29] |
| Internal way of communication about MFCA         | 2 (3%)                        | "Then, it was decided to address the issues by introducing the new process as "material flow activities” instead of using the name MFCA. Therefore, MFCA was positioned as the calculation of material loss, independently from cost accounting." [10] |
| Multi-unit and multi-level team composition      | 1 (1%)                        | "For Alpha, what really shone was the team composition for MFCA implementation. The team was comprised of members from multiple relevant units and they then comprised various levels so that decision making can be done more easily. In other words, multi-unit and multi-level team composition.” [70] |
| Show monetary effect due to MFCA                 | 1 (1%)                        | "It was decided that improvement effect (monetary amount) for visualized loss was reflected to the cost or allocated upon confirmation of the effect from implementation of the actual countermeasures for improvements.” [54] |
| Evaluate performance due to MFCA                 | 1 (1%)                        | "Tanabe Seiyaku has introduced MFCA into its performance evaluation, which is critically important because linking MFCA data to performance evaluation means that it formally recognised that improvement arising from MFCA data contributed to its organisation.” [61] |
| Recognize usefulness                             | 1 (1%)                        | "The company considered that on-site operators themselves needed to recognize the usefulness of MFCA and utilize it as a tool for improvement at sites. It also considered that MFCA would be embedded if MFCA implementation were achieved at the on-site level, in cooperation with the on-site staff, and together with a small-scale successful experience shared by the on-site staff.” [31] |
| Collaboration with supplier                      | 1 (1%)                        | "Canon successfully achieved introducing MFCA through collaboration with its supplier in order to concurrently reduce cost and environmental impacts by technological innovation.” [30] |

(Continues)
### Success factors for a constant application of MFCA

| Factor                                      | 3 (4%) | 2 (6%) | 1 (6%) | Note                                                                 |
|---------------------------------------------|--------|--------|--------|----------------------------------------------------------------------|
| Show benefits                               |        |        |        | "The accounting manager mentioned that it was critically important to know the amount of the potential financial benefit from reducing materials losses at each process through implementing MFCA." [61] |
| Execute improvement discoveries             | 3 (4%) | 1 (3%) | 1 (6%) | "As OMRON KURAYOSHI Corporation had already experienced a lot of improvement activities, its improvement approach after the visualization of loss was speedily implemented and it has achieved the result shown in Figure 9.1." [32] |
| Right people                                | 2 (3%) | 2 (6%) | 2 (11%)| "The success of JBC’s MFCA application was facilitated by the availability of an environmental taskforce and the EPI system implemented." [09] |
| Integrate in MCS                            | 2 (3%) | 2 (6%) | 2 (11%)| "As a result, it was found that by combining MFCA with its ERP system, Tanabe Seiyaku has integrated materials flow cost data into the corporate financial information system and promoted improvement activities that use MFCA." [61] |
| Show value of loss                          | 2 (3%) | 1 (3%) | 1 (6%) | "An advantage of MFCA application was that losses (per process and for overall processes) and impact of improvement measures through investments etc. could be expressed in a monetary unit." [44] |
| Integration in target setting               | 1 (1%) | 1 (3%) | 1 (6%) | "MFCA was positioned as a method to help achieve the target values for the production innovation indices." [10] |
| Integration in innovation process           | 1 (1%) | 1 (3%) | 1 (6%) | "Company A successfully achieved results because it introduced MFCA as the major method for supporting its production innovation activities." [10] |
| Low effort                                  | 1 (1%) | 0 (0%) | 0 (0%) | "If the staff is required to spare considerable time on MFCA analysis, a sense of stagnation tends to prevail at sites. Therefore, it is important to conduct MFCA analysis with minimum effort." [31] |

### Obstacles concerning the implementation of MFCA

| Obstacle                                      | 6 (8%) | 6 (17%) | 5 (28%) | Note                                                                                                                                 |
|-----------------------------------------------|--------|---------|---------|-------------------------------------------------------------------------------------------------------------------------------------|
| Effort to get data                           |        |         |         | "... the collection of physical information turned out to be a major challenge for EMA [MFCA] implementation. In particular, precise measurement of energy and auxiliary consumption at the production and supply process levels was difficult and in several cases required the use of estimated values." [63] |
| Accounting system is not sufficient for MFCA | 4 (5%) | 2 (6%)  | 0 (0%)  | "In the case study, authors have faced several organizational and accounting difficulties in applying the MFCA methodology. Generally, the SMEs have traditional accounting thinking, which accounts only monetary information and a lack of a clear flow chart of the production process in physical unit and/or a lack of independent cost centres emerges." [22] |
| Knowledge about process required              | 2 (3%) | 2 (6%)  | 1 (6%)  | "When applying the MFCA method within a plant manufacturing ceramic tiles of different sizes, colors, and glazes, the reconstruction of material flows was mainly based on the detailed knowledge of the manufacturing process and its individual stages." [12] |
| Resistance of employees                      | 1 (1%) | 1 (3%)  | 1 (6%)  | "He [manager] also found distrust of the new MFCA method among plant workers, who asked questions such as what they could get from this new method, whether there was any need to conduct analysis using such an unfamiliar method, and what the differences were between MFCA and the existing cost accounting?" [10] |
### Obstacles concerning the implementation of MFCA

| Obstacle                                                                 | Alpha (1%) | Beta (3%) | Gamma (0%) | Note                                                                                                                                                                                                                                                                                                                                 |
|--------------------------------------------------------------------------|------------|-----------|------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Collaboration with supplier necessary                                    | 1          | 1         | 0          | "Another critical barrier concerns vendor constraints. Before the new production run, Alpha needs to get their vendors to agree to supply the new pre-cut material size. An agreement between Alpha and the vendors must be achieved because this affects their "mother" coil supply, distribution and prior order stocks." [70] |
| Effort for MFCA analysis                                                  | 1          | 0         | 0          | "If the staff is required to spare considerable time on MFCA analysis, a sense of stagnation tends to prevail at sites." [31]                                                                                                                                                                                                        |
| Obstacles concerning a constant application of MFCA                      |            |           |            |                                                                                         |                                                                                                                                  |
| MFCA requires time and effort                                            | 5 (7%)     | 4 (11%)   | 4 (22%)    | "As a future issue, innovation will be necessary in ensuring that the data input activities for the MFCA analysis will not be overlapped with existing management activities." [27]                                                                                                                              |
| Reliability of MFCA data                                                 | 4 (5%)     | 4 (11%)   | 2 (11%)    | "Costs data come from the company report, though we have to admit that due to lack of information collection monitoring, the data may be incomplete and piecemeal." [67]                                                                                                                                 |
| Defining of suitable MFCA parameters                                     | 3 (4%)     | 2 (6%)    | 0 (0%)     | ‘As a characteristic of calculation, in case of the made-to-order production or a wide variety of products in small quantities, multiple types of products were normally punched out from a single plate. Therefore, it was difficult to determine the raw material amount for a single product to conduct the MFCA analysis.’ [33] |
| Limited availability of data                                             | 2 (3%)     | 2 (6%)    | 2 (11%)    | "Production records relating to the quantity of input materials and related costs used in each production batch is unavailable in the books of Hope Brewery’" [07]                                                                                                                                 |
| Improvement measures require specific know how and/or some investment    | 2 (3%)     | 2 (6%)    | 1 (6%)     | ‘Although, normal loss from this process is larger portion of blow molding process than defective products, to reduce normal loss, some detail in machine specification and some investment are required.’ [21]                                                                                     |
| Change of team members                                                   | 1 (1%)     | 1 (3%)    | 1 (6%)     | ‘The network surrounding MFCA greatly changed and the MFCA activities themselves became stagnant after 2011, because the staff that promoted the introduction and spread of MFCA had left.’ [10]                                                                                                                                |
| Attention to MFCA declined over time                                     | 1 (1%)     | 1 (3%)    | 1 (6%)     | ‘Although the midterm objective of reducing waste to zero was maintained, new targets like doubling productivity and halving energy consumption were added to midterm business plan. As a result, the new targets attracted more attention than reducing loss cost, and as MFCA had been entrusted to each in-house company, its use gradually declined.’ [10] |
| Resistance of staff to follow MFCA cycle                                 | 1 (1%)     | 1 (3%)    | 1 (6%)     | ‘…some company staff says that to find out this waste and eliminate it has been done in the past and is still being done, as if they were wringing water out of a dry towel, and it is impossible to do more.’ [56]                                                                                                         |
| Dependency on supply chain                                               | 1 (1%)     | 1 (3%)    | 0 (0%)     | ‘For Alpha, it had to adjust its new production run according to the vendor’s supply availability, indicative of the relatively low bargaining power of Alpha. As a consequence of this, cost savings and waste reduction that could have been realised earlier were somewhat delayed.’ [70] |
| No support from authorities                                              | 1 (1%)     | 1 (3%)    | 0 (0%)     | ‘Alpha was fortunate to have MPC [Malaysia Productivity Corporation], a Japanese technical expert and local consultants to assist it for its pilot projects on MFCA, but other SMEs may not be so fortunate. In fact, even Alpha itself may no longer have the privilege of this assistance for its own future and larger scale MFCA projects.’ [70] |

Note: The numbers in brackets refer to the citation numbers (the left column) of case studies listed in Appendix 1 in Supporting Information S5.
that comprise a financial component are described in 42%/42%/44% (31/15/8 of the 73/36/18) of the examined case studies. In Table 3 we provide exemplary quotes concerning positive financial effects of MFCA. In 58%/58%/56% of the case studies, no financial effects of MFCA are described.

4.3.2 Environmental effects of MFCA

18%/19%/17% (13/7/3 of 73/36/18 case studies) explicitly reported a reduction of waste as a result of the application of MFCA. The examples in Table 3 give an overview of the breadth of the results achieved through MFCA.

71%/69%/67% of the 73/36/18 case studies did not describe environmental effects of MFCA; however, this does not mean that environmental effects due to MFCA did not occur. Almost all of the case studies where environmental effects were described also illustrated financial effects. Although MFCA is a tool for environmental management, financial effects are mentioned almost twice as often as environmental effects in the case studies.

4.3.3 Strategic effects and the effects of MFCA on decision-making

The results from MFCA were used as strategic input for decision-makers. In one case (METI, 2011g), the MFCA analysis led to the awareness of a certain service that could be offered which could bring significant potential for expansion. We identified the enhancement of the decision-making process, strategic input, and increased competitiveness as three effects of MFCA with strategic relevance as depicted in Table 3. 14%/17%/28% (10/6/5 out of 73/36/18) of the case studies explicitly report that MFCA supports or improves decision-making. 82%/81%/67% of the 73/36/18 case studies made no statement about strategic or decision-making effects of MFCA.

4.3.4 Other effects of MFCA

53/23/12 of the 73/36/18 case studies (73%/64%/67%) mention one or more positive contributions of MFCA to their business (see Table 3). Further effects of MFCA described in the analyzed case studies were “MFCA as a tool to search for improvements” and “MFCA changed the perception.” Moreover, through MFCA the employees shared information better, companies enjoyed a more positive external reputation, there was increased employee participation, and employees could more easily convince top management to undertake environmentally friendly changes.

Again, as with the reasons for applying MFCA, plenty of effects were attributed to MFCA. Some of these effects were expected, but quite often the effects experienced were not in the scope of the aforementioned reasons for applying MFCA. Particularly, strategic effects were not anticipated when originally considering MFCA. It could be assumed that when more considerations for success factors and obstacles are taken when implementing and applying MFCA, then the effects of MFCA will be stronger and more numerous. However, this conclusion cannot be drawn from a meta-analysis of case studies, as it is not clear whether each single case study completely described all success factors, obstacles, and all effects. Therefore, this case studies analysis only listed the aforementioned success factors, obstacles, and effects.

4.4 Actions resulting from MFCA

When describing actions, it should be noted that MFCA only provides information in the form of monetary and quantitative units, although the actions are still carried out on the basis of further information not derived from MFCA. 39/13/6 companies (53%/36%/33%) reported measures that they have taken, or plan to carry out, due to the results of the MFCA analysis. 13/3/2 companies say that they have identified specific measures for improvement, some of which were described explicitly: “[I]t was necessary to consider an option of selecting wood materials that did not contain knots before the processing […]” (METI, 2011f). In detail, the following actions were taken or considered (53 occurrences in total) as listed in Table 4.

Interestingly, subsample 2 (referred articles) shows proportionally fewer specific actions than the full sample. One reason for this could be that non-academic sources focus more on the specific outcome and the subsequent steps resulting from a measure such as the application of MFCA.

4.5 Outlook that companies gave in respect to their use of MFCA

All case studies either directly or indirectly recommended considering the success factors and obstacles described in the section above. Half of the case studies (36/9/5 out of 73/36/18) explicitly mentioned what should or would be considered in the company’s MFCA activities. 17/2/1 expressed a desire to expand the area where MFCA is applied, and nine of the full sample wanted to improve the application of MFCA in their company. Aside
### Table 3  Financial, environmental, strategic, and other effects of MFCA

| Sub-category: Main reasons | Number of studies/occurrences | Illustrative quotes |
|---------------------------|-------------------------------|---------------------|
|                           | Full sample (73 cases) | Subsample 1 (36 cases) | Subsample 2 (18 cases) |
| **Financial effects**     |                               |                        |                       |
| Cost reduction            | 22 (30%)                      | 13 (36%)               | 7 (39%)               | “Cost reduction was 128 million yen from 2005 (the launch year) to 2009” [31]. Simultaneously, positive economic impacts were seen from reduced purchased price, less operations, less purchased amount of operating materials, less handling costs of sludge, waste oil and waste fluid.” [30] |
| Financial analysis on material loss | 8 (11%)                      | 2 (6%)                 | 1 (6%)                | “Through MFCA analysis, the impact of defective products could be identified not only in terms of yield rate, volume of defective products, and residual volume, but also in terms of total cost.” [43] |
| Investments made          | 5 (7%)                        | 3 (8%)                 | 1 (6%)                | “Especially in this project, MFCA was employed as a company decision-making tool, which led to 700 million yen of improvement measures and capital investments.” [24] |
| Material loss in monetary units | 1 (1%)                        | 0 (0%)                 | 0 (0%)                | “This suggested that 8,400 yen was disposed of every month from the nickel plating process. Likewise, it was necessary to consider these losses in combination with the waste management costs (5,500 yen).” [37] |
| **Environmental effects** |                               |                        |                       |
| Waste reduction           | 13 (18%)                      | 7 (19%)                | 3 (17%)               | “… a significant more emissions reduction (73% reduction) was achieved than initially targeted in the company’s Environmental Voluntary Action Plan” [29]. “The sludge volume was reduced by 50% through improvements based on the MFCA analysis. Furthermore, volume of oil and abrasive powder used in the grinding process were reduced by 40% and by 50%, respectively.” [30] |
| Improvements              | 6 (8%)                        | 4 (11%)                | 1 (6%)                | “As a result, optimal, environmentally-friendly cutting parameters were developed to create a cleaner and more sustainable manufacturing process.” [03] |
| Measurement of waste      | 2 (3%)                        | 0 (0%)                 | 0 (0%)                | “… it became clear that the visualization of energy by CO₂ conversion and of water resources in actual used amount is necessary to be continuously monitored in the future as an approach to reduce associated environmental impacts.” [54] |
| Systematic approach       | 2 (3%)                        | 2 (6%)                 | 2 (11%)               | “… by integrating financial performance evaluation with MFCA data, it has in effect constructed a management control system that enables company-wide environmental conservation-oriented activities to be conducted systematically.” [10] |
| Attention to environmental issues | 1 (1%)                        | 1 (3%)                 | 1 (6%)                | “Material Flow Cost Accounting system can mitigate the probability of dysfunctional decision making, particularly for investment decisions, assist managers in directly filtering out energy or material waste, and enhance the accuracy of product cost evaluations.” [01] |
| **Strategic effects**     |                               |                        |                       |
| Decision support          | 10 (14%)                      | 6 (17%)                | 5 (28%)               | “The Nitto Denko’s case proved that MFCA could serve as a management effective tool for business decisions in the following aspects: MFCA clarifies issues and potential solution for these issues; and MFCA enables appropriate capital investment and secures a budget for such investment.” [24]; “Through in-depth understanding of “quantity × unit cost”, it became possible to understand the adverse effects of proceeding with business based on intuition.” [49] |

(Continues)
### TABLE 3 (Continued)

| Strategic effects                  | 4 (5%) | 2 (6%) | 2 (11%) |
|-----------------------------------|--------|--------|---------|
| Strategic input                   |        |        |         |
| Increased competitiveness          | 1 (1%) | 1 (3%) | 1 (6%)  |
| Better calculation basis          | 28 (38%) | 13 (36%) | 6 (33%) |

> “In regard to products designed in other companies, the additional value of Press Manufacturer A will be realized through its proposals to customers from the viewpoint of "material loss." [34]

> “In conclusion, applying MFCA and DOE helped both increase product quality and reduce the adverse environmental impacts of the case study company’s production process, saving costs and improving its competitiveness.” [03]

> “… total improvement measures were simulated using the simple MFCA calculation tool” [44]. “The following impacts were identified through the MFCA implementation: All input costs, product costs, and material loss costs were clarified; Breakdown of cost for material losses per process was also clarified; Improvement measures could immediately be simulated; and Transparency of problematic areas was increased.” [35]. “MFCA can be used to quantitatively understand advantage and disadvantage between outsourcer and the parties jointly engaged in the project.” [47]

> “Out of this first MFCA cycle the development and implementation of more than 50 improvement projects resulted.” [17]

> “… using the concept of MFCA, the useless materials in the stock are reflected as negative products, which are excluded from the orders’ allocation objectives. … The problem is actualized, and the necessity for an improvement solution is apparent.” [72]

> “In recent three years, the corporation has gone through significant technological innovation and management improvement with the help of MFCA.” [67]

> “MFCA analysis made it possible to set clear targets for a total yield rate rather than the individual yield rates, and that the ground was fostered in which each employee was able to propose improvements from the operations that they were engaged in.” [33]

**Note:** The numbers in brackets refer to the citation numbers (the left column) of case studies listed in Appendix 1 in Supporting Information S5.

From these plans, the companies contemplated using MFCA as an analysis tool, using MFCA in the supply chain, and including material flow analysis in design and development activities.

### 4.6 Lessons learned from the use of MFCA

In 10/7/2 out of the 73/36/18 case studies, various lessons learned from applying MFCA are detailed. The authors of the case studies explicitly describe what is to be considered for the effective application of MFCA. Some refer to the application itself, while others stress the effects of MFCA. They emphasize checking the usefulness of measured variables in a company’s specific MFCA application, focusing on areas with higher chances to identify improvements, including the supply chain into the MFCA analysis, linking MFCA with ERP system, linking MFCA with a reward system, and relaying success stories of MFCA.

### 4.7 Contribution of cost accounting to industrial ecology

Among other objectives, an aim of this study was to examine if accounting could contribute to industrial ecology by analyzing the MFCA accounting method in practice. One idea for industrial metabolism is “[…] the whole integrated collection of physical processes […]” (Ayres, 1998, p. 3). Cost accounting techniques such as MFCA may contribute to this idea of industrial ecology when applied in companies, and particularly beyond the
TABLE 4 Specific actions resulting from MFCA which were mentioned at least four times

| Sub-category                        | Number of studies/occurrences | Illustrative quotes                                                                 |
|-------------------------------------|------------------------------|-------------------------------------------------------------------------------------|
|                                     | Full sample (73 cases)       | Subsample 1 (36 cases) Subsample 2 (18 cases)                                      |
| Identification of improvements      | 13 (18%)                    | 3 (8%) 2 (11%)                                                                       |
|                                     | "It led to an opportunity to build a mechanism that enables to propose improvement toward optimization that covers suppliers to OER [OMRON RELAY & DEVICES Corporation] in the entire supply chain." [54] |
| Implementation of loss analysis     | 9 (12%)                      | 5 (14%) 1 (6%)                                                                      |
|                                     | "Nitto Denko implemented ‘waste/loss analysis’ and ‘improvement measures’ based on the MFCA results and achieved improvement by approximately 10%." [24] |
| Definition of measures to reduce waste | 6 (8%)                       | 0 (0%) 0 (0%)                                                                      |
|                                     | "With respect to loss reduction, it is probably effective to minimize material loss by improving the yield ratio and reducing waste generation during the reactive process, and to lower the system costs by shortening the washing time and decreasing manual operations in the switch-cleaning process." [28] |
| Establishment of mechanism to propose improvements | 4 (5%)                      | 3 (8%) 1 (6%)                                                                       |
|                                     | "The accumulated costs of material losses strongly support the decision of the EPI taskforce to facilitate employee training in relation to waste reduction and to establish a suggestion scheme that includes awards and bonuses for employee ideas about further improvement." [09] |
| Improvement of processes            | 4 (5%)                       | 2 (6%) 1 (6%)                                                                       |
|                                     | "Improvements were made to both processes by recycling of sand from shell-removal process and wax in de-wax process." [23] |

Note: The numbers in brackets refer to the citation numbers (the left column) of case studies listed in Appendix 1 in Supporting Information S5.

boundaries of a single company, which means throughout the supply chain. In the examined case studies, companies reported that through the application of MFCA they

1. identified new areas for improving material efficiency in the supply chain;
2. could identify improvements in a more systematic way in the supply chain;
3. realized that MFCA must be expanded across the whole supply chain.

Canon Inc. (METI, 2011c) describes the advantage of expanding MFCA to the whole supply chain as follows: "The glass material supplier and Canon shared the information related to material losses and cooperatively worked to reduce the losses. This collaboration brought about positive environmental, economic and technological impacts, enhancing market competitiveness and realizing a win-win relationship between the glass material supplier and Canon." (METI, 2011k). One case study (Herzig, 2012) explicitly reports that MFCA supports the vision of zero waste—a key concept of industrial ecology. Several case studies (METI, 2011b; 2011d; 2011e; 2011h; 2011i; 2011j; Nakajima, Kokubu, Kokuryo, Nashioka, & Goto, 2003) described the improvement opportunities in the entire supply chain (upstream and downstream) as a result of the deployment of MFCA. The importance of the supply chain in an MFCA analysis was recognized and led to the introduction of ISO 14052 in 2017 (ISO, 2017).

5 | CONCLUSION

The results above clearly show what effects companies experience when they apply MFCA and that accounting can contribute to industrial ecology. Other environmental management accounting tools (Burritt et al., 2002) lead to similar effects, and likewise have various success factors and obstacles. A unique aspect of MFCA is its deep embedding into a company’s cost accounting system, and its fixed and systematic approach toward uncovering hidden costs and needless waste—as stated by various companies in the case study. On the face of it, one could assume that companies are eager to use MFCA, but the opposite appears to be true (Christ & Burritt, 2015). We estimate that only a few hundred companies worldwide have fully integrated MFCA into their MCS over the last 20 years (Günther et al., 2016a). Indeed, despite its development in Germany, a survey of German accounting Chairs revealed that the tool has not yet been nationally diffused in academia (Günther, Rieckhof, Schrack, & Walz, 2016b).

Interestingly, even academic disciplines like industrial ecology do not cover MFCA. From our case studies analysis, we draw the conclusion that this limited interest has nothing to do with the practical results of MFCA, but rather that environmental issues are not highly significant for the vast majority of companies and business managers whose actions would require exceeding legal obligations. For CEOs, profit maximization, increasing of shareholder value, and growth in terms of higher sales guide their actions and decisions. In order to introduce environmental issues into top-level
Management priorities, these issues must present a clear and direct connection to one of the three aforementioned guidelines. Even if this connection is demonstrated, it may nevertheless rank behind legal issues, sales, human resources, and production issues. By synthesizing 73/36/18 MFCA case studies, we were able to show that MFCA could indeed influence on higher-prioritized issues—especially concerning profit maximization and strategy. An industrial ecology approach would be enriched by incorporating MFCA. This view is supported by Journeault (2016), who states that “preliminary evidence that different eco-control practices support different environmental capabilities and that their simultaneous use seems necessary to support the implementation of a complete set of environmental capabilities.”

In this paper we wanted to find out the effects experienced by companies in practice following the application of MFCA, and the potential relevance of MFCA for industrial ecology. The hypothesis is that MFCA helps companies to better perform in terms of costs, and in terms of environmental damage; thereby raises the potential of industrial ecology. The analysis of the case studies showed that some companies experienced improvements in terms of costs, or in terms of reduced environmental damage, or both. Across all examined studies there were neither contradictions, nor major differences in the statements about the nature and usage of MFCA. The case studies either repeated certain issues, or they complement each other regarding a certain item. Methodologically, by synthesizing 73/36/18 case studies, we took 73/36/18 different and incomplete views of MFCA and built a rich and more complete picture of this accounting method. As a result, and following Noblit and Hare (1988), we created a new whole of the sum of the constituent parts.

The examined case studies confirm that the application of MFCA stimulates effects within a company and could contribute to a higher awareness of topics and processes in the light of industrial ecology. Combined, the case studies provide a rich picture of what MFCA strives for and what companies can expect when they apply MFCA. While a single case study often described only certain effects of MFCA, taken from a specific viewpoint (e.g., strategic aspects about MFCA are described in only 13/7/6 of the 73/36/18 case studies), our research made this picture clearer.

### TABLE 5  Overview of drivers, issues, and outcomes of MFCA in terms of business management and industrial ecology

| Characteristics of MFCA | Determinants (rationale for applying MFCA) and success factors | Outcomes of MFCA |
|-------------------------|---------------------------------------------------------------|------------------|
| In terms of business management | Main reasons for choosing MFCA: Economic reasons (such as reduction of costs or identification of hidden costs), organizational reasons (such as using MFCA as a tool to enhance quality or improvement of processes) | Financial effects of MFCA: Cost reduction, financial analysis of material loss, investments made due to MFCA, material loss in monetary units. |
| Specific reasons for choosing MFCA: Discover hidden costs, identify management problems; improve a process, increase productivity, measure costs of non-product output, reduce costs, source for decision-making, underline economic value of physical amounts | Strategic input and enhancement of decision-making process through MFCA; Decision support, increased competitiveness, strategic input. | |
| Success factors for the implementation of MFCA: Include MFCA into ERP system, demonstrate monetary effect due to MFCA; evaluate performance due to MFCA | Specific actions due to MFCA: Establishment of mechanism to propose improvements, investment for improvement, investment was proposed. |
| Further effects of MFCA: Better calculation basis, identified improvement measures, identified key issues/problems, motivated for action. | Further effects of MFCA: Improvements (environmental) made. |

In terms of industrial ecology |

Main reasons for choosing MFCA: Environmental reasons (such as reduction of waste or reduction of environmental impact) | Environmental effects of MFCA: Attention to environmental issues, improvements (environmental), measurement of waste, systematic approach, waste reduction. |

Specific reasons for choosing MFCA: Get physical and monetary data about losses, identify material losses, identify sources for improvement, increase corporate environmental performance, reduce losses, take on flow-oriented perspective, use MFCA as a tool |

Specific actions due to MFCA: Definition of measures to reduce waste, employee awareness concerning loss will be improved, employee training for loss reduction is considered, feedback to product design on loss was given, identification of improvements, implementation of loss analysis, improvement mechanism will be examined, improvement of processes, input material specifications were improved, mechanism to eliminate loss was established, reduction of input material was planned. |

Success factors for the implementation of MFCA: Collaboration with supplier; internal communication about MFCA; management support; multi-unit and multi-level team composition; thorough preparation of MFCA processes; successful experience due to MFCA |

Further effects of MFCA: Improvements (environmental) made. |
established to propose improvements” to “processes were improved.” The added value of our research is the depiction of the nuances and the variety of information found in the case studies, thereby smoothing the shortcomings of the single case studies without diluting the original data. In 58%/58%/56% of the studies, no financial effects were mentioned, and 71%/67%/69% of the studies listed no environmental effects. Although we found many different effects of the application of MFCA, we could generalize from the data and extract characteristics of MFCA in terms of business management and in terms of industrial ecology. However, as mentioned previously, the reader should be aware that these insights are based on a limited availability of data, the described effects are tentative until such a time that more data is available.

Table 5 summarizes the categories presented in the results section and differentiates the characteristics of MFCA into economic and ecological considerations. Interestingly, MFCA works on both tracks; it could be launched as an economic tool to generate cost reductions and efficiency gains, or as an environmental management tool to reduce waste. As a result, whatever the reasons to apply MFCA, the outcomes generally demonstrate economic and ecologic improvements. Depending on the perspective, MFCA is either a tool for value creation where corporate environmental performance has a direct and positive impact on corporate financial performance, or could be deployed by firms with good financial performance to provide slack resources for activities such as an improvement in corporate environmental performance (Guenther & Hoppe, 2014).

In the results section we exhaustively list the possible effects of MFCA when applied in a company, thereby answering our research question about the effects of the application of MFCA in practice. Practitioners can use this list to prepare themselves when introducing and using MFCA in a company. Where the DIN-EN-ISO Standard No. 14051 describes the steps of how to implement and work with MFCA, our results add practical insights to the usage of MFCA. Indeed, as MFCA is a tool which also addresses the supply chain, it fits the concept of industrial ecology well. Further research on MFCA can use our enumeration of MFCA effects as a basis when examining certain aspects of MFCA usage. Moreover, research can use items from the list to develop a questionnaire or a structured interview about the use of MFCA. In order to raise the potential of industrial ecology, analysts conducting a material flow analysis, or a life cycle assessment, should consider applying MFCA to complement their analyses.

Although the statement that MFCA helps companies to better perform in terms of costs and in terms of reducing environmental damage is valid thus far, further research in this direction could fundamentally strengthen the hypothesis or lead to a refutation of the hypothesis. With this research we hope to reduce the gap between the fields of business management and industrial ecology (Hoffman et al., 2014) by raising the awareness of MFCA in both communities. We are looking forward to conducting further research which simultaneously considers the economic and ecologic effects of industrial activities—both within a company and throughout the whole supply chain.

ACKNOWLEDGMENTS
The authors thank the authors of the original MFCA case studies that they examined, and the anonymous reviewers and the editors for their valuable and helpful comments and suggestions. Open access funding enabled and organized by Projekt DEAL.

CONFLICT OF INTEREST
The authors have no conflict to declare.

ORCID
Matthias Walz  https://orcid.org/0000-0002-2657-2782
Edeltraud Guenther  https://orcid.org/0000-0001-6968-9238

REFERENCES
Ayres, R. U. (1998). Industrial metabolism: Work in progress. In C. J. M. Jeroen, van den Bergh, & M. W. Hofkes (Eds.), Theory and implementation of economic models for sustainable development (pp. 195–228). Dordrecht: Springer Netherlands.
Angell, I. O., & Smithson, S. (1991). Information systems management: Opportunities and risks, Part of the Information Systems Series book series (INSYS) (pp. 1–248). London: Springer Press. https://doi.org/10.1007/978-1-349-21555-3
Bakker, P. (2013). Accountants will save the world. Harvard Business Review Blog Network. Retrieved from https://hbr.org/2013/03/accountants-will-save-the-world
Berry, M. A., & Rondinelli, D. A. (1998). Proactive corporate environmental management: A new industrial revolution. The Academy of Management Executive, 12(2), 38–50.
Bullock, R. (1986). A meta-analysis method for OD case studies. Group & Organization Management, 11(1–2), 33–48.
Burritt, R. L., Hahn, T., & Schaltegger, S. (2002). Towards a comprehensive framework for environmental management accounting: Links between business actors and environmental management accounting tools. Australian Accounting Review, 12(27), 39–50.
Cepeda, G., & Martin, D. (2005). A review of case studies publishing in Management Decision 2003–2004: Guides and criteria for achieving quality in qualitative research. Management Decision, 43(6), 851–876.
Chang, S.-H., Chiu, A., Chu, C. L., Wang, T.-S., & Hsieh, T.-I. (2015). Material flow cost accounting system for decision making: The case of Taiwan SME in the metal processing industry. Asian Journal of Finance & Accounting, 7(1), 117–134.
Christ, K. L., & Burritt, R. L. (2015). Material flow cost accounting: A review and agenda for future research. Journal of Cleaner Production, 108(Part B), 1378–1389.
Cohen, M. J., & Howard, J. (2006). Success and its price: The institutionalization and political relevance of industrial ecology. Journal of Industrial Ecology, 10(1–2), 79–88.
METI (2011b). Case 6 Mitsubishi Tanabe Pharma Corporation. In METI (Ed.), Material Flow Cost Accounting – MFCA Case Examples 2011. Tokyo, Japan: Ministry of Economy, Trade and Industry of Japan.

METI (2011c). Case 7 Canon Inc. In METI (Ed.), Material Flow Cost Accounting – MFCA Case Examples 2011. Tokyo, Japan: Ministry of Economy, Trade and Industry of Japan.

METI (2011d). Case 8 Nagahama Canon Inc. In METI (Ed.), Material Flow Cost Accounting – MFCA Case Examples 2011. Tokyo, Japan: Ministry of Economy, Trade and Industry of Japan.

METI (2011e). Case 9 OMRON Corporation. In METI (Ed.), Material Flow Cost Accounting – MFCA Case Examples 2011. Tokyo, Japan: Ministry of Economy, Trade and Industry of Japan.

METI (2011f). Case 23 KODAI SANGYO CO., LTD. In METI (Ed.), Material Flow Cost Accounting – MFCA Case Examples 2011. Tokyo, Japan: Ministry of Economy, Trade and Industry of Japan.

METI (2011g). Case 27 Sanden Corporation. In METI (Ed.), Material Flow Cost Accounting – MFCA Case Examples 2011. Tokyo, Japan: Ministry of Economy, Trade and Industry of Japan.

METI (2011h). Case 29 Sanden Corporation Supply chain team. In METI (Ed.), Material Flow Cost Accounting – MFCA Case Examples 2011. Tokyo, Japan: Ministry of Economy, Trade and Industry of Japan.

METI (2011i). Case 30 Panasonic Ecology Systems Co., Ltd. Supply chain team. In METI (Ed.), Material Flow Cost Accounting – MFCA Case Examples 2011. Tokyo, Japan: Ministry of Economy, Trade and Industry of Japan.

METI (2011j). Case 31 OMRON RELAY & DEVICES Corporation. In METI (Ed.), Material Flow Cost Accounting – MFCA Case Examples 2011. Tokyo, Japan: Ministry of Economy, Trade and Industry of Japan.

METI (2011k). Ministry of Economy, Trade and Industry of Japan. (2011). Material flow costing—MFCA case examples 2011. Tokyo, Japan: Japanese Ministry of Economy, Trade and Industry. https://www.mjec.co.jp/mfca/document/pdf/MFCA2205_new.pdf

Mintzberg, H. (1979). An emerging strategy of “direct” research. Administrative Science Quarterly, 24(4), 580–589.

Mulrow, C. D. (1994). Systematic reviews—Rationale for systematic reviews. Bmj: British Medical Journal, 309(6954), 597–599.

Nakajima, M. (2006). The new management accounting field established by material flow cost accounting (MFCA). Kansai University Review of Business and Commerce, 8, 1–22.

Nakajima, M. (2020). The need of management accounting for problem-finding to develop management accounting for sustainability. Kansai University Review of Business and Commerce, 19, 1–13.

Nakajima, M., Kobuk, K., Kokuryo, Y., Nushioka, E., & Goto, F. (2003). Case Study II: Shionogi & Co Ltd. Paper presented at the International Symposium on Environmental Accounting.

Newig, J., & Fritsch, O. (2009). The case survey method and applications in political science. Paper presented at the APSA 2009 meeting on Case study meta-analysis: Methodological challenges and applications in the political sciences, Toronto. https://www.researchgate.net/publication/228162937_The_Case_Survey_Method_and_Applications_in_Political_Science

Noblitt, G. W., & Hare, R. D. (1988). Meta-ethnography: Synthesizing qualitative studies. London: Sage. https://www.worldcat.org/title/meta-ethnography-synthesizing-qualitative-studies/oclc/16647196

Norris, G. A. (2001). Integrating life cycle cost analysis and LCA. The International Journal of Life Cycle Assessment, 6(2), 118–120.

Oldenburg, K. U., & Geiser, K. (1997). Pollution prevention and... or industrial ecology? Environmental Accounting. New York: United Nations. Retrieved from Proceedings of International Symposium on Environmental Resources (Part B), 1255–1261.

Piekkari, R., Plakoyiannaki, E., & Welch, C. (2010). “Good” case research in industrial marketing: Insights from research practice. Industrial Marketing Management, 39(1), 109–117.

Sandeforski, M., Docherty, S., & Emden, C. (1997). Focus on qualitative methods qualitative meta synthesis: Issues and techniques. Research in Nursing and Health, 20(4), 365–371.

Scapens, R. W. (1990). Researching management accounting practice: The role of case study methods. The British Accounting Review, 22(3), 259–281.

Schmidt, M. (2015). The interpretation and extension of material flow cost accounting (MFCA) in the context of environmental material flow analysis. Journal of Cleaner Production, 108(Parl 130), 1310–1319.

Schmidt, M., & Nakajima, M. (2013). Material flow cost accounting as an approach to improve resource efficiency in manufacturing companies. Resources, 2(3), 358–369.

SCP/RAC, Regional Activity Centre for Sustainable Consumption and Production. (2015). MED TEST II: Reinforcing the national capacities for Material Flow Cost Accounting. https://www.switchmed.eu/en/news/news-1/med-test-ii-reinforcing-the-national-capacities-for-material-flow-cost-accounting. Accessed July 24, 2019.

Staubus, G. J., Sorter, G. H., & Horngren, C. T. (1963). Direct, relevant or absorption costing? The Accounting Review, 38(1), 64–74.

Thomas, J., & Harden, A. (2008). Methods for the thematic synthesis of qualitative research in systematic reviews. BMC Medical Research Methodology, 8(45), 1–10.

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British Journal of Management, 14(3), 207–222.

United Nations. (2015). Transforming our world: The 2030 agenda for sustainable development. New York: United Nations. Retrieved from https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf. Accessed August 19, 2020.

Van Berkel, R., Willems, E., & Lafleur, M. (1997). Development of an industrial ecology toolbox for the introduction of industrial ecology in enterprises—I. Journal of Cleaner Production, 5(1), 11–25.

Wagner, B. (2003). Developments of material flow cost accounting in Germany. In K. Kobuk (Ed.), Proceedings of International Symposium on Environmental Accounting 2003 (pp. 52–61). Kobe, Japan: Kansai Research Center Institute for Global Environmental Strategies IGES. Retrieved from https://pub.iges.or.jp/pub/proceedings-international-symposium. Accessed February 19, 2014.

Wagner, B. (2015). A report on the origins of material flow accounting (MFCA) research activities. Journal of Cleaner Production, 108(Part B), 1255–1261.

Walsham, G. (1995). Interpretive case studies in IS research: Nature and method. European Journal of Information Systems, 4(2), 74–81.
SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Walz M, Guenther E. What effects does material flow cost accounting have for companies? Evidence from a case studies analysis. J Ind Ecol. 2021;25:593–613. https://doi.org/10.1111/jiec.13064