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Abstract

From the perspective of material flow cost accounting (MFCA), which treats both material and financial flows within a company, this study proposes a corporate waste decomposition model to investigate the effects of material and financial factors on corporate waste generation. The proposed model decomposes waste into the material loss (waste ratio of raw materials [WRMat]), raw material-to-cost ratio (RtCR; material use efficiency), cost-to-sales ratio (or COGSR), total asset turnover ratio (TATR), leverage, and total equity. As an application, the waste decomposition analysis is performed using the log-mean Divisia index (LMDI) method, and 125 listed firms in 5 Japanese manufacturing sectors from 2010 to 2015 are analyzed. The LMDI results show that the RtCR, the most crucial term in MFCA, had the largest effect on increases in waste generation as of 2015; however, this effect is not so robust among sectors over the years, implying that MFCA is valid mainly for specific companies/sectors or years. Also, corporate environmental burdens (waste and carbon emission) are likely to be correlated negatively with leverage and positively with total equity in the models, implying that the financial and stock markets have an essential role in deciding corporate environmental burdens.

Keywords: material flow cost accounting; waste efficiency; Japanese manufacturing industries; log-mean Divisia index

JEL codes: Q53, Q56

1. Introduction

Material flow cost accounting (MFCA) is defined as a "tool for quantifying the flows and stocks of materials in processes or production lines in both physical and monetary units" (International Organization for Standardization [ISO] 14051, 2011, p.3). MFCA is part of environmental management accounting (EMA) and focuses on a revised production cost calculation for material flow (Jasch, 2003). MFCA measures the cost of material losses (waste), which is ignored in traditional cost accounting and provides much motivation to reduce materials and increase resource efficiency. The application of MFCA in the business process will enhance sustainable consumption and production, which is Goal 12 of the United Nations (UN)'s Sustainable Development Goals (United Nations Development Programme, 2015). Recently, the ISO published two international standards of MFCA, ISO 14051 (2011) and ISO 14052 (2017).

MFCA has been gradually disseminated worldwide since the international standards were published. In the MFCA literature, there were 24 *Journal of Cleaner Production* (JCLP) articles out of a total of 35 articles with the keyword "material flow cost accounting" published before December 2017, according to the Web of Science provided by Clarivate Analytics (Table 1; Yagi and Kokubu, 2018). The use of MFCA in various countries can be identified by examining the literature: Austria (Jasch, 2003, 2006), the Czech Republic (ISO 14051, 2011), Germany (ISO 14051, 2011; Wagner, 2015), Japan (ISO 14051, 2011; Kokubu and Kitada, 2015), the Philippines (ISO 14051, 2011), Thailand (Chompu-Inwai et al., 2015; Jakrawatana et al., 2016; Kasemset et al., 2013), and South Africa (Fakoya and Van Der Poll, 2013), as well as China, India, Korea, Malaysia, and Vietnam (Kokubu and Nakajima, 2018). Although the MFCA literature provides many case studies, MFCA has not fully spread across the board at this time (Yagi and Kokubu, 2018). The exception is Japan, where the Ministry of Economy, Industry, and Trade (METI) promoted MFCA between 2000 and 2010. In response to ISO 14051, Japan submitted its new proposal and headed a project towards MFCA standardization. Even in Japan, however, only 17.2% of the responding companies in the manufacturing sector have implemented MFCA (at the strategic level) as of 2015, according to a survey conducted by Kitada et al. (2016).

The reason why MFCA has only been disseminated at a moderate pace is likely that firms do not fully recognize its importance. MFCA can contribute to enhancing resource efficiency as well as reducing costs. However, as discussed by Christ and Burritt (2015), discussions that measure waste efficiency among companies and industries are lacking in the literature. Therefore, the motivation of this study is to examine how MFCA can improve material efficiency at the company or industry level rather than to conduct a case study for MFCA at the factory level.

As research motivation, this study aims to contribute to the MFCA literature by proposing and applying the resource efficiency model to sustainability and cleaner production at the corporate or industry level. Case or model studies in the MFCA literature often consider only the process level (i.e., the "quantity center" in MFCA terms) rather than the corporate or industry level. Hence, MFCA studies lack a perspective that shows how to estimate waste efficiency and its determinants at the corporate or industry level. Note that this study will also contribute to JCLP because JCLP is the leading journal of the MFCA field (Table 1).

This study proposes a decomposition analysis model of corporate waste generation that considers non-financial factors (waste and raw materials used) and common financial factors (cost of goods sold [COGS], sales, total assets, and total equity). The identity model of this study follows Yagi and Managi (2018), as the corporate version of Kaya identity (Kaya and Yokobori, 1997), integrating absolute and relative corporate environmental performance (CEP) and corporate financial performance (CFP). Specifically, the identity model decomposes corporate waste into a waste ratio of raw materials (WRMat), a raw materials-to-cost ratio (RtCR; raw materials divided by COGS), a cost-to-sales ratio (or COGS ratio [COGSR]), total asset turnover ratio (TATR), leverage, and total equity. Among the terms, RtCR is considered important from the perspective of MFCA because MFCA can simultaneously manage both raw materials and cost.

As an application of the identity model, this study adopts the log-mean Divisia index (LMDI) method, following Yagi and Managi (2018). This study analyzes 125 listed firms in 5 Japanese manufacturing sectors from 2010 to 2015, as compared with Yagi and Managi (2018), who propose the corporate carbon dioxide (CO_2) model examining 225 listed firms in Japanese manufacturing sectors from 2011 to 2015. The LMDI results of the entire sample from 2010 to 2015 show that the largest positive factors for waste generation are RtCR as the non-financial factor (unlike in Yagi and Managi (2018)) and equity as the size factor (as in Yagi and Managi (2018)); however, although the effect of the size factor is likely to be robust, that of RtCR is not very robust among sectors. Therefore, MFCA should have great potential to reduce corporate waste generation only for specific companies/sectors (e.g., the material, capital goods, and food sectors) or outlier years.

This paper is structured as follows. Section 2 explains the literature on MFCA and previous studies of decomposition analysis as the background for the model in this study. Section 3 proposes a model of waste decomposition analysis, and Section 4 shows decomposition by LMDI as the application method. Section 5 examines corporate data in the Japanese manufacturing sector as an application of the model and shows the estimated results with discussions. Section 6 provides conclusions.

2. Background of the MFCA approach

2.1 Importance of MFCA and previous research

MFCA is defined as a "tool for quantifying the flows and stocks of materials in processes or production lines in both physical and monetary units" (ISO 14051, 2011, p.3). MFCA is part of EMA and focuses on a revised production costs calculation for material flow (Jasch, 2003). According to Wagner (2015), the concept of input/output mass balances has been discussed since the 1920s. The MFCA movement was triggered by a German textile company (Kunert) that pioneered the first corporate environmental reports in 1991. Subsequently, research on EMA progressed through researchers and international organizations, such as a working group of the UN Division for Sustainable Development and the International Federation of Accountants (IFAC) (IFAC, 2005). In 2007, the Japanese committee (including METI) proposed a new work item on MFCA to the ISO. The first standard of MFCA, ISO 14051 (2011; general framework), and the second standard, ISO 14052 (2017; practical implementation in a supply chain), were published in 2011 and 2017, respectively. Since the publication of ISO 14051, MFCA has been gradually disseminated. For example, the Asian Productivity Organization (APO) has conducted a project to expand the use of MFCA in Asia (APO, 2012). The MFCA project, mainly led by the APO, started in 2010, and e-learning courses were held in 2011 and 2012, with 225 participants from 10 countries. As another example, in ASEAN countries, the Vietnam Productivity Center introduced MFCA to 3 small and medium enterprises in 2011, and the number increased to 40 firms in 2017 (as expected) (Kokubu and Nakajima, 2018).

In recent years, MFCA research has gradually accumulated in the literature. We searched the published journal articles in the Web of Science (Clarivate Analytics's journal database) using the keyword "material flow cost accounting" (accessed December 2017) and reviewed 24 of the 35 articles found in the topic search (the 24 articles were all published in JCLP) (Table 1; Yagi and Kokubu, 2018). Among the 24 articles, only two papers (Jasch, 2003; 2006) were published in the 2000s, with the remaining 22 published after 2011. These studies can be roughly divided into four categories: discussion and review of MFCA (e.g., Christ and Burritt, 2015; Guenther et al., 2015; Rieckhof et al., 2015; Schaltegger and Zvezdov, 2015; Wagner, 2015); case studies (specific applications) of MFCA (e.g., Jakrawatana et al., 2016; Jasch, 2015; Kasemset et al., 2013; Kokubu and Kitada, 2015; Mahmoudi et al., 2017; Sulong et al., 2015); development models of MFCA and their application (e.g., Bautista-Lazo and Short, 2013; Bierer et al., 2015; Chompu-Inwai et al., 2015; Fakoya and Van Der Poll, 2013; Kurdve et al., 2015; Nakano and Hirao, 2011; Schmidt, 2015; Schmidt et al., 2015; Wan et al., 2015; Zhou et al., 2017); and questionnaire surveys (Nakajima et al., 2013; the questionnaire surveys in Kitada et al. (2016) and Yagi and Kokubu (2018) were not among the 24 surveyed).

Although the number of MFCA studies is increasing and spreading worldwide, little evidence has been provided on the precise number of companies that have introduced MFCA into their operations. Japan is one of the world's leading countries in terms of the use of MFCA, and METI has been promoting MFCA in Japan since the 2000s. Nakajima et al. (2013) and Kitada et al. (2016) conducted questionnaire surveys about MFCA implementation in the Japanese manufacturing sector (where the target firms are all listed firms) in 2012 (356 responses) and 2015 (250 responses). The results show that MFCA had been introduced in only 7 firms (2.0%) as of 2012 and 43 firms (17.2%) (at the strategic level) as of 2015.

Recently, Yagi and Kokubu (2018) focus on Thailand (as a developing country that hardly uses MFCA) and examine the degree of (general) material flow management as a preparatory step on the way to full MFCA. The questionnaire survey collects 101 responses from 596 non-financial listed companies in Thailand as of October 2017. The results show that 58% manage MF information, whereas 50%, 49%, 29%, and 24% disclose the amounts of total waste, hazardous waste, raw materials consumed, and recycled waste, respectively. Therefore, companies in developing countries such as Thailand tend to consider hazardous waste management more than resource efficiency, implying that there are specific stages in which different environmental measure companies may be interested.

According to Nakajima et al. (2013) and Kitada et al. (2016), the penetration rate of MFCA still appears to be low. Also, companies in developing countries are less likely to be concerned about resource efficiency than about hazardous waste management (Yagi and Kokubu, 2018). This study believes that one reason why MFCA is not currently widespread is that the effectiveness of MFCA has not been successfully conveyed to companies; if firms fully understood that MFCA provides effective results, then under market competition, they would try to take the initiative in adopting MFCA. Many individual studies have been performed on MFCA implementation (case studies and model studies), although no empirical study has been performed to show whether MFCA is useful for overall resource efficiency. As discussed by Christ and Burritt (2015), few discussions are found in the literature on measures of waste efficiency among companies and industries. Indeed, among the 24 articles, no models are proposed to compare corporate waste generation or efficiency at the industry level. Thus, to disseminate MFCA into corporate practice, this study believes that more persuasive evidence of the effectiveness of MFCA must be provided.

2.2 How MFCA works in a simple model

MFCA is a management tool for both material and financial flows. Figure 1 shows a simple MFCA model of material and financial flows in a manufacturing firm, following Yagi and Managi (2018) (note that this study represents "cash flow" in Yagi and Managi (2018) as financial flow, because "cash flow" is a specific term in corporate accounting). Based on the MFCA perspective, Yagi and Managi (2018) have conducted a decomposition analysis of corporate CO_2 and greenhouse gas emissions for Japanese manufacturing firms, integrating CEP and CFP into their identity model.

Figure 1 represents material and financial flows by straight and dotted arrows, respectively. Material flow considers how raw materials are processed into products (i.e., used), which are divided into the positive product (i.e., regular product) and the negative product (i.e., waste). Herein, "negative product" refers to all waste generation, including valuables (e.g., reuse and recycle) and waste exhaust (or final disposal outside a firm), for both industrial and ordinary business waste. Meanwhile, the financial flow considers COGS, which is sales minus gross margin (selling, general, and administrative expenses [SGA] and profit). MFCA divides COGS into four-types costs, material cost (MC), energy cost (EC), system cost (SC; other costs such as labor cost), and waste management cost (WMC), in each quantity center, depending on the material flow. Therefore, MFCA indeed divides COGS into the following seven costs: MC, EC, SC, and WMC for the negative product; and MC, EC, and SC for the positive product.

Note that in regards to the system boundaries of MFCA, the minimum measurement point for material and financial flows is at the process level (i.e., each quantity center). Then, each measurement at the process level can be accumulated at the company level. Thus, although the relationship among material flow and costs may appear complicated, depending on the business characteristics, MFCA can be applied to any industry as far as each process (or each quantity center) can measure the material and financial flows.

Regarding the material flow in Figure 1, raw materials for the negative product (in the upper part) are bought from suppliers by MC, processed to waste by EC and SC (EC&SC), and managed by WMC, thus leading to waste generation. Meanwhile, raw materials for the positive product (in the lower part) are bought from suppliers by MC, processed to a positive product by EC and SC (EC&SC), and then managed by SGA, for selling to customers. Note that there is no WMC for the positive product because it is not wasted.

Meanwhile, regarding the financial flow in Figure 1, it is important to note that customers bear all costs (which should be equal to sales) and both of the negative and positive products cause sales. Therefore, the negative product causes a financial flow (from sales) to WMC, EC&SC, and MC, in that order. Similarly, the positive product causes a financial flow (from sales) to SGA, EC&SC, and MC, in that order. Note that profit comes directly from sales. Also of importance in Figure 1, note that such corporate activities are supported by total assets from the resource perspective (such as cash, capital, and inventory), following Yagi and Managi (2018). Herein, total assets consist of debt and equity, which are funds from the financial and stock markets, respectively.

3. Model

3.1 Motivation of this study

The purpose of this study is to propose a decomposition analysis model that integrates financial factors and raw materials used to investigate the determinants of corporate waste generation. According to ISO 14051 (2011), MFCA is a management tool that can assist organizations in better understanding the potential environmental and financial consequences of their material and energy use practices and provide them with opportunities to achieve both environmental and financial improvements via changes in those practices. Under MFCA, the flows and stocks of materials within an organization are traced and quantified in physical units (e.g., mass, volume), and the costs associated with those material flows are also evaluated (ISO 14051, 2011). The resulting information can motivate organizations and managers to seek opportunities to simultaneously generate financial benefits and reduce adverse environmental impacts (ISO 14051, 2011).

The research contribution of this study to the MFCA literature is the proposal and application of the resource efficiency model at the corporate level. The MFCA literature proposes various MFCA models and conducts case studies but does not propose the efficiency model at the corporate or industry level, even though MFCA was originally a company-wide accounting method, considering COGS (Figure 1).

The model of this study is an identity model of corporate waste efficiency which integrates CEP and CFP, following Yagi and Managi (2018), as in the recent literature on corporate social responsibility (CSR). In the literature, a key issue is to examine the relationship between corporate social performance (CSP) and CFP—that is, "does it pay to be green?" (Ambec and Lanoie, 2008). Recently, the focus has shifted gradually from CSP to CEP such as sulfur oxides/nitrogen oxides and CO_2 emissions. Specifically, the two main measures for CEP are absolute CEP (or absolute emissions, such as emission reductions) and relative CEP (or relative emissions; the ratio of emissions over a particular variable), whereas the two main measures for CFP are accounting-based (e.g., return on assets [ROA]) and market-based (e.g., Tobin's q) (Busch and Lewandowski, 2017; Yagi and Managi, 2018).

Recent literature focuses mainly on CO_2 emission (or greenhouse gas emission) as a measure of CEP. It tends to support the positive relationship between CEP and CFP (i.e., CEP improves CFP, and vice versa). However, Busch and Lewandowski (2017) argue that the relationship depends on the measurement of CEP and CFP, based on their meta-analysis of 68 estimates between 2010 and 2016. Among the four indicators (i.e., two of CEP and two of CFP), the relationship between relative CEP and market-based CFP is most likely to be positive. Motivated by the ambiguous relationship among the four indexes regarding CO_2 emissions, Yagi and Managi (2018) consider integrating absolute and relative CEP and accounting-based CFP into a simple model that aims to be a corporate version of Kaya identity (Kaya and Yokobori, 1997).

3.2 Corporate waste equation

This study follows the identity equation models of Yagi and Managi (2018) as a corporate version of Kaya identity (Kaya and Yokobori, 1997). Kaya identity is one of the most famous models for macro analysis in the literature of the environmental and energy fields, explaining the amount of CO_2 emissions (as absolute CEP) by energy use (Energy), gross domestic product (GDP), and population (Pop).

$$CO_2 = \frac{CO_2}{Energy} \cdot \frac{Energy}{GDP} \cdot \frac{GDP}{Pop} \cdot Pop \tag{1}$$

CO_2, on the left-hand side (LHS), denotes the amount of total CO_2 emissions (direct and indirect emissions; Scope 1+2), whereas the first through fourth terms on the right-hand side (RHS) are carbon intensity (CO_2 per Energy), energy intensity (Energy per GDP), GDP per capita (GDP per Pop), and the national population (Pop) as the scale variable. Note that the terms on the RHS cancel each other out, becoming CO_2 on the LHS.

Yagi and Managi (2018, p.1482) argue that Kaya identity is not "suited for corporate analysis because GDP (value added) and population, in particular, are rarely considered in corporate accounting." Regarding data accessibility, individuals outside certain firms often access common accounting variables (such as COGS and SGA) but usually cannot access detailed information at the operational level (such as material flow). With recent environmental, social, and governance information disclosures (e.g., the Bloomberg database), non-financial information has gradually become available. Thus, based on the information on corporate CO_2 emissions (CO_2) and energy use (Energy), Yagi and Managi (2018) propose a corporate version of Kaya identity.

$$\begin{aligned} CO_2 &= \frac{CO_2}{Energy} \cdot \frac{Energy}{COGS} \cdot \frac{COGS}{Sales} \cdot \frac{Sales}{Assets} \cdot \frac{Assets}{Equity} \cdot Equity \\ &= CO_2Int \cdot EneInt \cdot COGSR \cdot TATR \cdot AtER \cdot Equity \end{aligned} \tag{2}$$

Equation 2 divides CO_2 into the following six terms: carbon intensity (CO_2 per Energy; CO_2Int), energy intensity (Energy per COGS; EneInt), cost-to-sales ratio (COGS per Sales; COGSR), total asset-to-equity ratio (AtER) as leverage, TATR (total assets [Assets] per Equity), and total equity (Equity) as another scale variable.

Thus, the carbon and energy intensities (CO_2Int and EneInt) are material factors, whereas the third through sixth terms are common financial factors. Although basic interpretations of these terms are provided, Yagi and Managi (2018) perform an additional interpretation from a management perspective. The COGSR can be considered an indicator of operational pressure, because relatively higher COGS (numerator) values mean that firms depend more on the operating process in corporate accounting than on other financial factors. The TATR can be interpreted as market pressure, because a higher sales (numerator) value means that the firm will face a larger market. The AtER can be considered financial market pressure, because more debt (part of the numerator) from the financial market leads to a higher AtER. Also, equity can be considered stock market pressure, simply because the total equity consists of funds from the stock market.

Equation 2 is useful for corporate carbon analysis but not directly for MFCA analysis, because it does not consider waste and raw materials used. Recently, certain companies have started disclosing information related to MFCA, including the total amounts of waste and raw materials used. Thus, considering the data availability, this study proposes the following corporate waste equation to investigate the determinants of corporate waste generation:

$$\begin{aligned} W &= \frac{W}{Material} \cdot \frac{Material}{COGS} \cdot \frac{COGS}{Sales} \cdot \frac{Sales}{Assets} \cdot \frac{Assets}{Equity} \cdot Equity \\ &= WRMat \cdot RtCR \cdot COGSR \cdot TATR \cdot AtER \cdot Equity \end{aligned} \tag{3}$$

where W, on the LHS, denotes the amount of total waste produced and the first through sixth terms on the RHS are cancel each other out and equal W. Note that the third to sixth terms are the same as in equation 2.

The first term on the RHS is the waste ratio of (raw) materials (WRMat), which is W divided by the amount of raw materials used (Material). The WRMat is an essential indicator of waste inefficiency (i.e., an aggregate material loss) in MFCA. Important measures to decrease the WRMat are establishing a purchase plan, product design, production technology, and so on. The WRMat usually takes a value between 0% and 100%.

The second term is the raw material-to-COGS ratio (RtCR), which indicates the quantity of cheap raw materials that are purchased (as compared to COGS). This study considers RtCR the most crucial indicator of resource efficiency in the equation, because it connects the degrees of material use to financial factors. If the RtCR represents increasing corporate waste (W) in a certain firm, then this study believes that there is a potential benefit to implementing MFCA, because MFCA has the potential to simultaneously generate financial benefits and reduce adverse environmental impacts. Thus, the WRMat and RtCR are non-financial items (with W and Material as material factors).

4. LMDI for corporate waste decomposition

The identity equation is easy to understand because there is no error term but relatively difficult to apply the empirical analysis (e.g., regression analysis) for the same reason. For equation 3, this study adopts an index decomposition analysis (IDA), following Yagi and Managi (2018) (for the literature of IDA and LMDI, see Ang, 2004, 2015; Ang and Zhang, 2000). The energy and environmental fields often use IDA for identity equations such as the IPAT equation (where the environmental impact is expressed by the product of population, affluence, and technology) and Kaya identity (e.g., for recent studies, see Cansino et al., 2015; Chong et al., 2015; Fujii and Managi, 2013; Kwon et al., 2017; Wang et al., 2014; Wang et al., 2017). In the accounting field, ROA is a popular tool for decomposing profits using the identity approach.

The advantage of the identity approach is the lack of theoretical errors in the calculation and the presence of few calculation assumptions. Future predictions of variables are possible to some extent, although the approach is highly sensitive to exogenous shock because of the lack of error terms. The disadvantage of the identity approach is that it is not very suitable for a regression model, again because it contains no error terms (Lozano and Gutiérrez, 2008).

The LMDI decomposes the change in the waste amount between two periods (such as the base (beginning) of another year) into each term of the corporate waste equation (equation 3). Suppose that there are i firms among j industries between years 0 (the base) and t, LMDI decomposes the sum of the changes in waste (ΔW) of firm i in industry j as of year t as follows:

$$\begin{aligned}\sum_i \Delta W_{ij}^t &= \sum_i \left(W_{ij}^t - W_{ij}^0\right) \\ &= \sum_i \Delta WRMat_{ij}^t + \sum_i \Delta RtCR_{ij}^t + \sum_i \Delta COGSR_{ij}^t + \sum_i \Delta TATR_{ij}^t \\ &\quad + \sum_i \Delta AtER_{ij}^t + \sum_i \Delta Equity_{ij}^t\end{aligned} \tag{4}$$

where

$$\Delta WRMat_{ij}^t = \begin{cases} 0, & if\ W_{ij}^t - W_{ij}^0 = 0 \\ L\left(W_{ij}^t, W_{ij}^0\right)\ln\left(WRMat_{ij}^t \big/ WRMat_{ij}^0\right), & if\ W_{ij}^t - W_{ij}^0 \neq 0 \end{cases} \tag{5}$$

$$\Delta RtCR_{ij}^t = \begin{cases} 0, & if\ W_{ij}^t - W_{ij}^0 = 0 \\ L\left(W_{ij}^t, W_{ij}^0\right)\ln\left(RtCR_{ij}^t \big/ RtCR_{ij}^0\right), & if\ W_{ij}^t - W_{ij}^0 \neq 0 \end{cases} \tag{6}$$

$$\Delta COGSR_{ij}^t = \begin{cases} 0, & if\ W_{ij}^t - W_{ij}^0 = 0 \\ L\left(W_{ij}^t, W_{ij}^0\right)\ln\left(COGSR_{ij}^t \big/ COGSR_{ij}^0\right), & if\ W_{ij}^t - W_{ij}^0 \neq 0 \end{cases} \tag{7}$$

$$\Delta TATR_{ij}^{t}=\begin{cases}0, & if\ W_{ij}^{t}-W_{ij}^{0}=0\\ L\left(W_{ij}^{t},W_{ij}^{0}\right)\ln\left(TATR_{ij}^{t}/TATR_{ij}^{0}\right), & if\ W_{ij}^{t}-W_{ij}^{0}\neq 0\end{cases} \tag{8}$$

$$\Delta AtER_{ij}^{t}=\begin{cases}0, & if\ W_{ij}^{t}-W_{ij}^{0}=0\\ L\left(W_{ij}^{t},W_{ij}^{0}\right)\ln\left(AtER_{ij}^{t}/AtER_{ij}^{0}\right), & if\ W_{ij}^{t}-W_{ij}^{0}\neq 0\end{cases} \tag{9}$$

$$\Delta Equity_{ij}^{t}=\begin{cases}0, & if\ W_{ij}^{t}-W_{ij}^{0}=0\\ L\left(W_{ij}^{t},W_{ij}^{0}\right)\ln\left(Equity_{ij}^{t}/Equity_{ij}^{0}\right), & if\ W_{ij}^{t}-W_{ij}^{0}\neq 0\end{cases} \tag{10}$$

$$L\left(W_{ij}^{t},W_{ij}^{0}\right)=\frac{W_{ij}^{t}-W_{ij}^{0}}{\ln\left(W_{ij}^{t}/W_{ij}^{0}\right)} \tag{11}$$

Each term (ΔWRMat, ΔRtCR, ΔCOGSR, ΔTATR, ΔAtER, and ΔEquity) represents a contribution to the change in waste (ΔW) and denotes how much each term explains ΔW. This study adopts a relative contribution ratio for equations 4-11, by taking absolute values of the change rates. This indicates how much each index contributes to the change in waste (ΔW) (for details, see Appendix A and Yagi and Managi, 2018).

5. Application to the Japanese manufacturing sectors

5.1 Data

This study first confirms how to apply the actual dataset to the LMDI. An LMDI requires seven items in equation 3, which are the LHS (W) and six terms on the RHS (WRMat, RtCR, COGSR, TATR, AtER, and Equity). Note, however, that this study needs only six terms, namely each of the numerators and denominators (W, Material, COGS, Sales, Assets, and Equity). Regarding time, the LMDI needs data for at least two years (the base and the particular year) and does not need the data of the intermediate period.

Regarding the data, this study (equation 3) examines 125 Japanese manufacturing companies based on the Global Industry Classification Standard (GICS) industry classification from 2010 to 2015, where the monetary unit is millions of US dollars [USD] (at nominal value) (see Appendix B for descriptive statistics). Meanwhile, the previous study, Yagi and Managi (2018) (for equation 2), examines 225 Japanese manufacturing companies based on the Tokyo Stock Exchange industry classification from 2011 to 2015, where the monetary unit is Japanese yen (at nominal value).

Regarding how to choose the target firms, this study targets the manufacturing sectors that disclose information on waste and raw materials used. Based on the data from Bloomberg Professional Services (accessed July 2017) with the four digits of the GICS from 1510 to 4530, Table 2 shows there are 1,860 listed firms in the 9 manufacturing sectors in Japan. Among them, 314 firms (16.9%) provided information on the total amount of waste for the six years, and 148 firms (8.0%) disclosed the raw materials used for those years. Note that the accounting variables of 143 of the 148 firms were obtained. Among the 143 firms, the study targets the following five sectors, which have more than 10 sample firms: #1510 materials (Mat) (38 firms), #2010 capital goods (Cap) (35 firms), #2520 consumer durables & apparel (CDur) (11 firms), #3020 food beverage & tobacco (Food) (24 firms), and #4520 technology hardware & equipment (Tech) (17 firms).

Accordingly, balanced panel data on 125 sample firms from 2010 to 2015 (750 observations) are used (see Supplementary material for the raw dataset (a comma-separated values file of the 125 firms) in this study, including information on sector, firm (identification numbers without names), year, total waste (TotalWaste), raw materials used (RawMatUsed), COGS, sales (Revenue), assets (TotAssets), and equity (TotEqty)). Note that this study removed one company from #1510 that had more than 10 times the normal fluctuation of raw material used in the observed years (probably because of a record error).

Note that sample selection bias may have occurred, because this study selects companies more willing to disclose information. Although this study does not consider whether the 125 target companies need or implement MFCA, a certain number of them may be introducing MFCA, following Kitada et al. (2016)'s survey. Regarding the sample selection bias, this study expects that, if it has chosen a greater number of companies more likely to implement MFCA, RtCR (raw materials divided by COGS) in equation 3 may have less impact on waste generation. This is because MFCA will have more opportunities to review raw material consumption and costs, potentially leading to lower waste generation.

5.2 Results of the LMDI

Table 3 and Figure 2 show the average values of the relative contribution ratios in the entire sample and in each sector. In the entire sample, the average relative contribution ratios are 25.2% for WRMat, 24.4% for RtCR, 4.5% for COGSR, 14.5% for TATR, 11.4% for AtER, and 20.0% for equity. These findings indicate that, on average, the WRMat and RtCR (which are material factors) explain approximately half of the waste variations (49.6% = 25.2% + 24.4%). The remaining variations (50.4%) depend on the financial factors (COGSR, TATR, AtER, and equity). Similarly, regarding each sector, approximately half of the waste variations are explained by the material factors (WRMat and RtCR): 48.6% (24.1% + 24.5%) for #1510 (Mat), 47.7% (25.7% + 22.0%) for #2010 (Cap), 51.8% (30.3% + 21.5%) for #2520 (CDur), 53.2% (25.0% + 28.2%) for #3020 (Food), and 49.5% (23.9% + 25.6%) for #4520 (Tech). Thus, the remaining variations (approximately half) are explained by the financial factors. Among the financial factors, equity (firm size) has the largest ratio (22.0% [#1510], 18.9% [#2010], 20.2% [#2520], 17.8% [#3020], and 20.3% [#4520]) whereas COGSR (operational pressure) has the smallest ratio (3.8% [#1510], 4.8% [#2010], 4.1% [#2520], 4.3% [#3020], and 5.7% [#4520]). Because MFCA can be employed to improve the WRMat and RtCR, these results support the potential of MFCA for corporate operations.

Regarding the estimated results of the LMDI, Table 4 shows changes in the amount of waste from 2010 (the base year) through 2015 ($\Sigma\Delta W$ (LHS) in columns 1 to 5; the unit is kilotonnes [kt]). Figure 3 also shows the results for the entire sample (upper left) and for each sector (upper right for #1510 [Mat]; middle left for #2010 [Cap]; middle right for #2520 [CDur]; lower left for #3020 [Food]; lower right for #4520 [Tech]).

Regarding the entire sample as of 2015 (column 5 in Table 4), waste is increased by 6770.2 kt, decomposed into 772.7 kt for the WRMat, 8206.6 kt for the RtCR, −1114.3 kt for the COGSR, 462.5 kt for the TATR, −5709.8 kt for the AtER, and 4152.4 kt for equity. Thus, the RtCR has the largest positive impact on corporate waste as of 2015, whereas the TATR has the smallest impact. Because MFCA can reduce the amount of raw materials used and then improve the RtCR (raw materials divided by COGS), the implementation of MFCA allows the entire sample to reduce waste at the aggregate level.

Regarding each sector as of 2015, the components that have the largest positive impact are different in each sector: RtCR for #1510 (Mat), #2010 (Cap), and #3020 (Food) (4452.0 kt, 2307.7 kt, and 1569.7 kt, respectively), AtER for #2520 (CDur; 329.2 kt), and equity for #4520 (Tech; 225.8 kt). This result implies that the implementation of MFCA will be most beneficial for the material, capital goods, and food beverage and tobacco sectors (#1510, #2010, and #3020) as of 2015.

5.3 Discussions

Regarding the estimated results, the relative contribution ratio and the LMDI seemingly contradict each other, but they in fact are consistent, as follows. The former represents how much each term fluctuates relatively, on average, and hence the two non-financial factors and four financial factors fluctuate to the same extent (49.6% and 50.4%) over the years. Meanwhile, the LMDI represents the aggregated impact (or amount) of each term on the waste (ΔW) in a certain sector. If a certain term of the LMDI has a large absolute value in a sector, it can be either because of certain large companies or the overall tendency of the sector. Hence, the large value may be an outlier. For example, although RtCR has the largest value (8206.6 kt) in the entire sample as of 2015, this may be an outlier due to certain large companies or may be robust throughout the sectors.

This study further confirms the relationship among LMDI terms to investigate whether the results of the LMDI are consistent among sectors over the years. Table 5 shows a correlation table of each term in the LMDI for the five sectors from 2011 to 2015 (25 observations). As in Figure 4, the correlation coefficients between the change in waste amount ($\Sigma\Delta$W) and each term are 0.847 at the 1% significance level for $\Sigma\Delta$WRMat, 0.271 insignificantly for $\Sigma\Delta$RtCR, −0.747 at the 1% significance level for $\Sigma\Delta$COGSR, −0.072 insignificantly for $\Sigma\Delta$TATR, −0.519 at the 1% significance level for $\Sigma\Delta$AtER, and 0.861 at the 1% significance level for $\Sigma\Delta$Equity. Thus, the change in waste amount ($\Sigma\Delta$W) is correlated significantly positively to the material loss ratio ($\Sigma\Delta$WRMat) and firm size ($\Sigma\Delta$Equity) and significantly negatively to the cost ratio ($\Sigma\Delta$COGSR) and leverage ($\Sigma\Delta$AtER), but not significantly correlated to the RtCR ($\Sigma\Delta$RtCR) or TATR ($\Sigma\Delta$TATR). Because the correlation between W (waste generation) and RtCR (raw materials divided by COGS) is positive but insignificant, the impact of RtCR is not robust for all sectors over the years, implying that MFCA (which manages both raw materials and costs) is not valid for all sectors as a means of reducing waste generation.

Table 6 compares the summary results of the entire sample in this study (upper for A1, B1, and C1; Equation 3) and in Yagi and Managi (2018) (lower for A2, B2, and C2; Equation 2), including the relative contribution ratio (A1 and A2), the LMDI of the entire sample (B1 and B2), and correlation coefficients of waste (C1) and CO_2 (C2). Note again that this study examines 125 Japanese manufacturing firms from 2011 to 2015 and Yagi and Managi (2018) examine 225 firms in 16 Japanese manufacturing sectors from 2010 to 2015.

The relative contribution ratios in this study (A1 in Table 6) are 49.6% for the non-financial factors ($\Sigma\Delta$WRMat and $\Sigma\Delta$RtCR) and 50.4% for the other financial factors, whereas those in Yagi and Managi (2018) (A2 in Table 6) are 39.7% for non-financial factors ($\Sigma\Delta CO_2$Int and $\Sigma\Delta$EneInt) and 60.3% for other financial factors. Therefore, the fluctuation of non-financial factors in Equation 3 (waste) tends to be larger than that in Equation 2 (CO_2), in Japanese manufacturing sectors.

Regarding the LMDI of the entire sample (B1 and B2 in Table 6), waste (ΣΔW) increases by 6770.2 kt as of 2015 in this study, whereas CO_2 (ΣΔCO_2) increases (indeed decreases) by −802.1 kt as of 2015 in Yagi and Managi (2018). Regarding common points, as the non-financial ratios both of numerator and denominator, ΣΔWRMat and ΣΔCO_2Int have modestly positive values (772.7 kt and 2922.5 kt, respectively); the cost ratio (ΣΔCOGSR) has modestly negative values (−1114.3 kt and −6350.5 kt, respectively); leverage has extremely negative values (−5709.8 kt and −7912.3 kt, respectively); and size (ΣΔEquity) has highly positive values (4152.4 kt and 45070.1 kt, respectively). Thus, the four determinants tend to be similar for both waste generation and CO_2 emissions in Japanese manufacturing sectors.

Meanwhile, regarding a different aspect of the LMDI, of the variables with a non-financial numerator and a financial denominator, ΣΔRtCR has a highly positive value (8206.6 kt), increasing waste generation, whereas ΣΔEneInt has a very negative value (−26036.3 kt), decreasing CO_2 emissions. This implies that in Japan, the balance between COGS and energy is regarded as important for reducing CO_2 emissions, but the balance between COGS and raw materials may not be taken into consideration as much, suggesting the potential impact of MFCA on waste generation.

In addition, TATR (ΣΔTATR), as the proxy for market pressure, has a slightly positive effect (462.5 kt) in this study but a negative effect (−8495.6 kt) in Yagi and Managi (2018). This suggests that higher market pressure leads to higher waste generation and lower CO_2 emissions, probably depending on the characteristics of products/services.

Finally, regarding correlation coefficients in Yagi and Managi (2018) (C2 in Table 6), the correlation coefficients of the change in CO_2 (ΣΔCO_2) are 0.226 insignificantly for carbon intensity (ΣΔCO_2Int), −0.011 insignificantly for energy intensity (ΣΔEneInt), −0.344 insignificantly for the cost ratio (ΣΔCOGSR), −0.431 at the 10% significance level for TATR (ΣΔTATR), −0.846 at the 1% significance level for leverage (ΣΔAtER), and 0.662 at the 1% significance level for size (ΣΔEquity). Thus, as a common point, both waste (C1) and CO_2 (C2) are correlated significantly negatively to leverage (AtER) and significantly positively to size factor (Equity), suggesting that leverage and size are robustly important, as in the LMDI results. In other words, the effects of the other terms in equations 2 and 3, respectively, are not very robust either for waste generation or CO_2 emissions.

6. Conclusions

This study aims to propose a corporate waste model to investigate the effects of material factors and financial factors on corporate waste generation from the MFCA perspective. The proposed identity model decomposes waste into material loss (WRMat), RtCR (material use efficiency), COGSR, TATR, leverage, and total equity. As an application of the model, this study performs waste decomposition analysis via the LMDI method, using a dataset of 125 Japanese manufacturing firms from 2010 to 2015.

In the model of this study, RtCR (raw materials divided by COGS) is considered important from the MFCA perspective because MFCA treats both raw materials (material flow) and COGS (financial flow) simultaneously to improve resource efficiency. The LMDI results of the entire sample (from 2010 to 2015) show that RtCR has the largest impact on the increase in waste generation as of 2015, suggesting that MFCA will have enormous potential to improve resource efficiency in Japan; however, the impact of RtCR is not so robust among all sectors over the years (according to the correlation coefficients). This implies that MFCA is likely to have potential for waste reduction mainly for specific companies/sectors (e.g., the material, capital goods, and food sectors) and for, in particular, specific sectors in specific, outlier years (e.g., 2015).

Regarding another characteristic of the results, the corporate environmental burdens (waste generation in this study and CO_2 emissions in Yagi and Managi (2018)) are likely to be correlated negatively with leverage and positively with total equity (firm size) in the models. This implies that the financial and stock markets have an important role to play in deciding corporate environmental burdens. Note that compared with Yagi and Managi (2018), this study finds that financial factors are relatively less likely to contribute to the fluctuation of waste generation (50.4%) than that of CO_2 emissions (60.3%) on sample average.

The model of this study has the advantage of being easy to interpret and adapt by using decomposition methods such as the LMDI. In addition, as demonstrated, the model can be applied at the corporate or industry level. A limitation of this study, however, is that the model can be further developed at the process level (quantity center; the factory and facility level). For example, the model used in this study only includes corporate accounting variables collected for general purposes (i.e., archival data). For the actual operation and potential measurements of MFCA, internal information and management processes will be required. However, this study does not measure the actual efficiency of corporate internal process (e.g., actual operations in each quantity center). Therefore, future studies should be able to provide a more specific demonstration of the potential benefits of MFCA implementation by carrying out more detailed analyses at the factory and facility level. Also, it is necessary to accumulate further empirical analysis from sources other than Japanese manufacturing sectors.

Appendix A. The relative contribution ratio

The relative contribution ratios in firm i as of year t are calculated in equations A1 and A2:

$$\frac{\left|\Delta WRMat_{ij}^{t}\right|}{Denom_{ij}^{t}}+\frac{\left|\Delta RtCR_{ij}^{t}\right|}{Denom_{ij}^{t}}+\frac{\left|\Delta COGSR_{ij}^{t}\right|}{Denom_{ij}^{t}}+\frac{\left|\Delta TATR_{ij}^{t}\right|}{Denom_{ij}^{t}}+\frac{\left|\Delta AtER_{ij}^{t}\right|}{Denom_{ij}^{t}}+\frac{\left|\Delta Equity_{ij}^{t}\right|}{Denom_{ij}^{t}}=100\% \quad \text{(A1)}$$

where

$$Denom_{ij}^{t}=\left|\Delta WRMat_{ij}^{t}\right|+\left|\Delta RtCR_{ij}^{t}\right|+\left|\Delta COGSR_{ij}^{t}\right|+\left|\Delta TATR_{ij}^{t}\right|+\left|\Delta AtER_{ij}^{t}\right|+\left|\Delta Equity_{ij}^{t}\right|. \quad \text{(A2)}$$

where Denom is a denominator for the sum of relative contributions. The sum of each term in equation A2 should be 100%, and no rate takes a negative value because of the use of absolute values. Note that this study does not calculate the relative contribution ratio when Denom = 0.

Appendix B. Descriptive statistics

Appendix Table A1 shows the descriptive statistics for the entire sample. Appendix Table A2 shows the aggregate data of the entire sample and the relative rates from 2010 (2010 = 100%) to 2015. Appendix Table A3 shows the aggregate data for each industry in the entire period. In the entire sample from 2010 to 2015 (Appendix Table A2), net increases in the basic variables are 21.4% for waste, 14.6% for raw materials used, −3.5% for COGS, −2.0% for sales, −5.3% for total assets, and 0.5% for equity. Thus, the sample firms tend to increase waste and raw materials used while decreasing COGS, sales, and total assets, indicating that the economies of the sample firms are shrinking slightly at the aggregate level.

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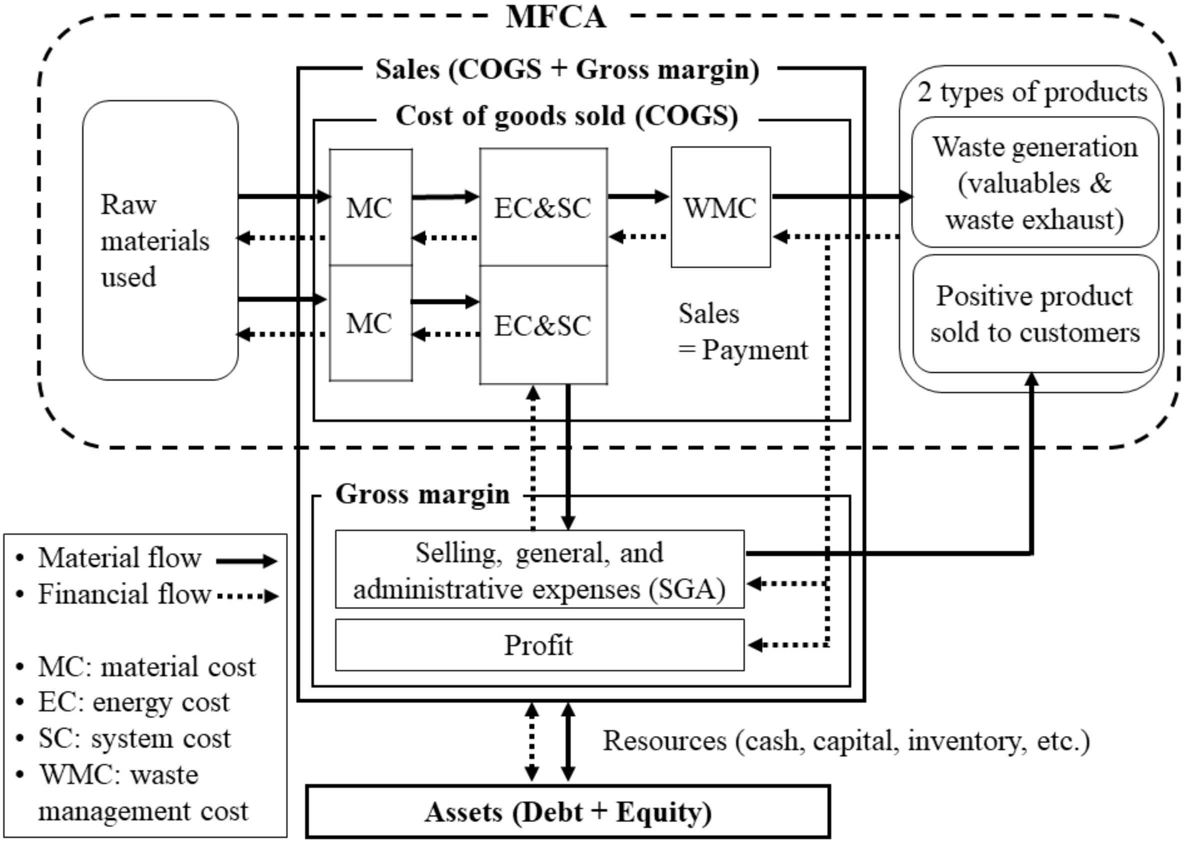

Figure 1. Material and financial flows in MFCA

Notes: This figure shows material flow (a straight arrow) and financial flow (a dotted arrow) in manufacturing firms from the MFCA perspective, following Yagi and Managi (2018). Regarding the material flow, raw materials in the upper part are bought by MC, processed by EC and SC (EC&SC), and managed by WMC. This leads to waste generation, which consists of valuables and waste exhaust. Meanwhile, raw materials used in the lower part are bought by MC, processed by EC and SC (EC&SC), managed by SGA, and then sold to customers (as the positive product). Regarding the financial flow, the customers' payments are equal to sales. These sales activities are supported by a firm's assets (debt + equity).

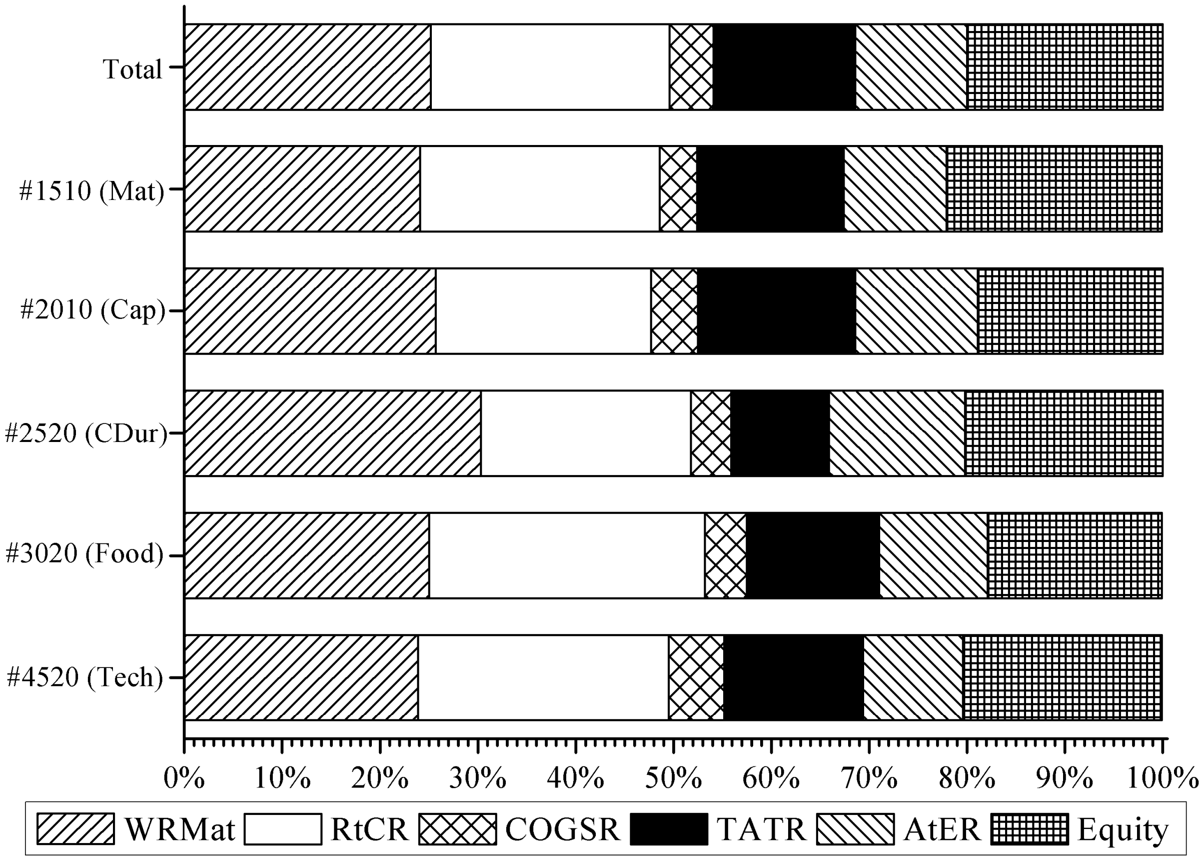

Figure 2. Average values of the relative contribution ratios in each sector

Note: See Table 3 for detailed values.

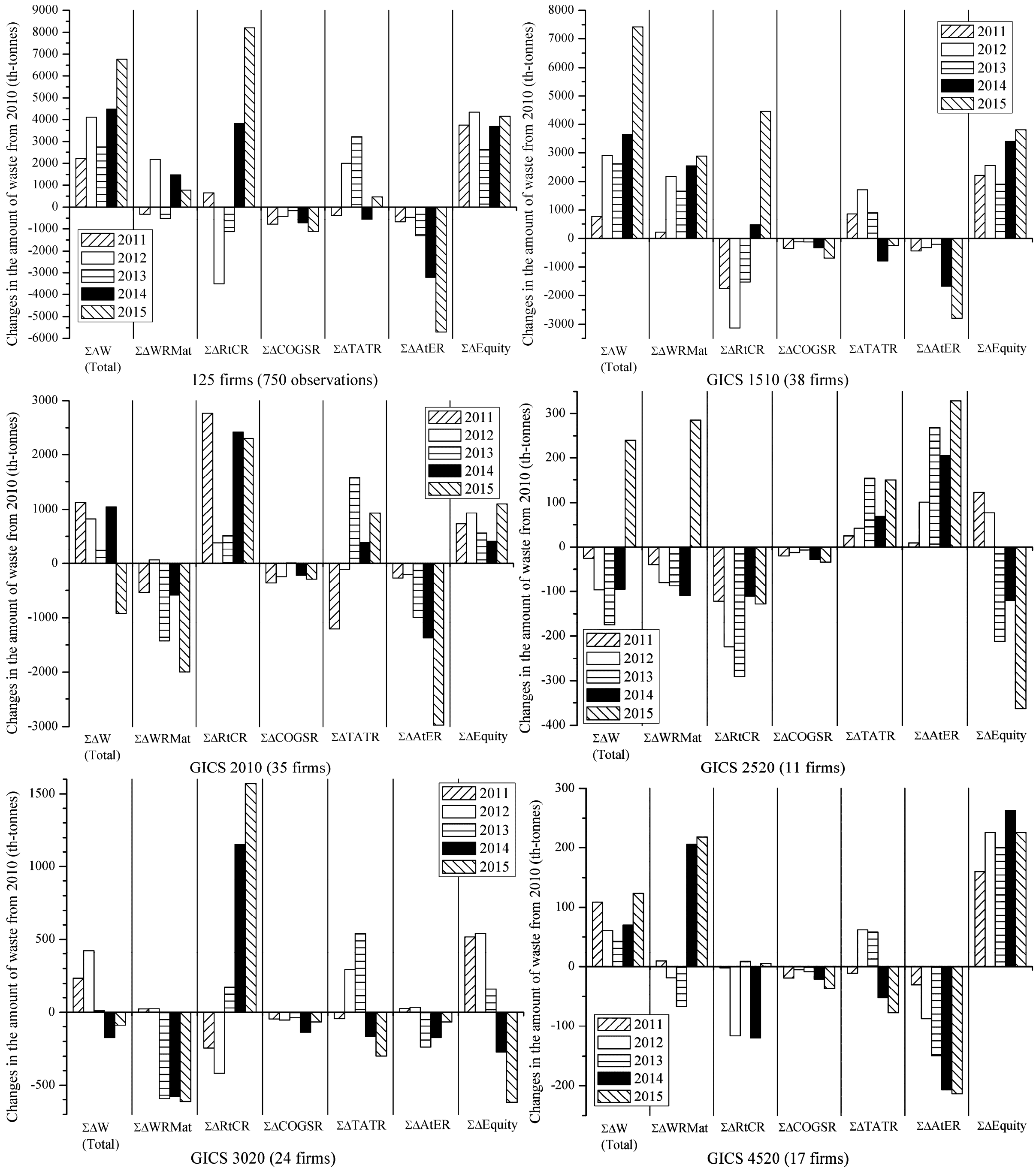

Figure 3. Changes in the amount of waste from 2010, estimated by the LMDI

Notes: Upper left for the entire sample; upper right for #1510 (Mat); middle left for #2010 (Cap); middle right for #2520 (CDur); lower left for #3020 (Food); and lower right for #4520 (Tech). See Table 4 for the detailed values.

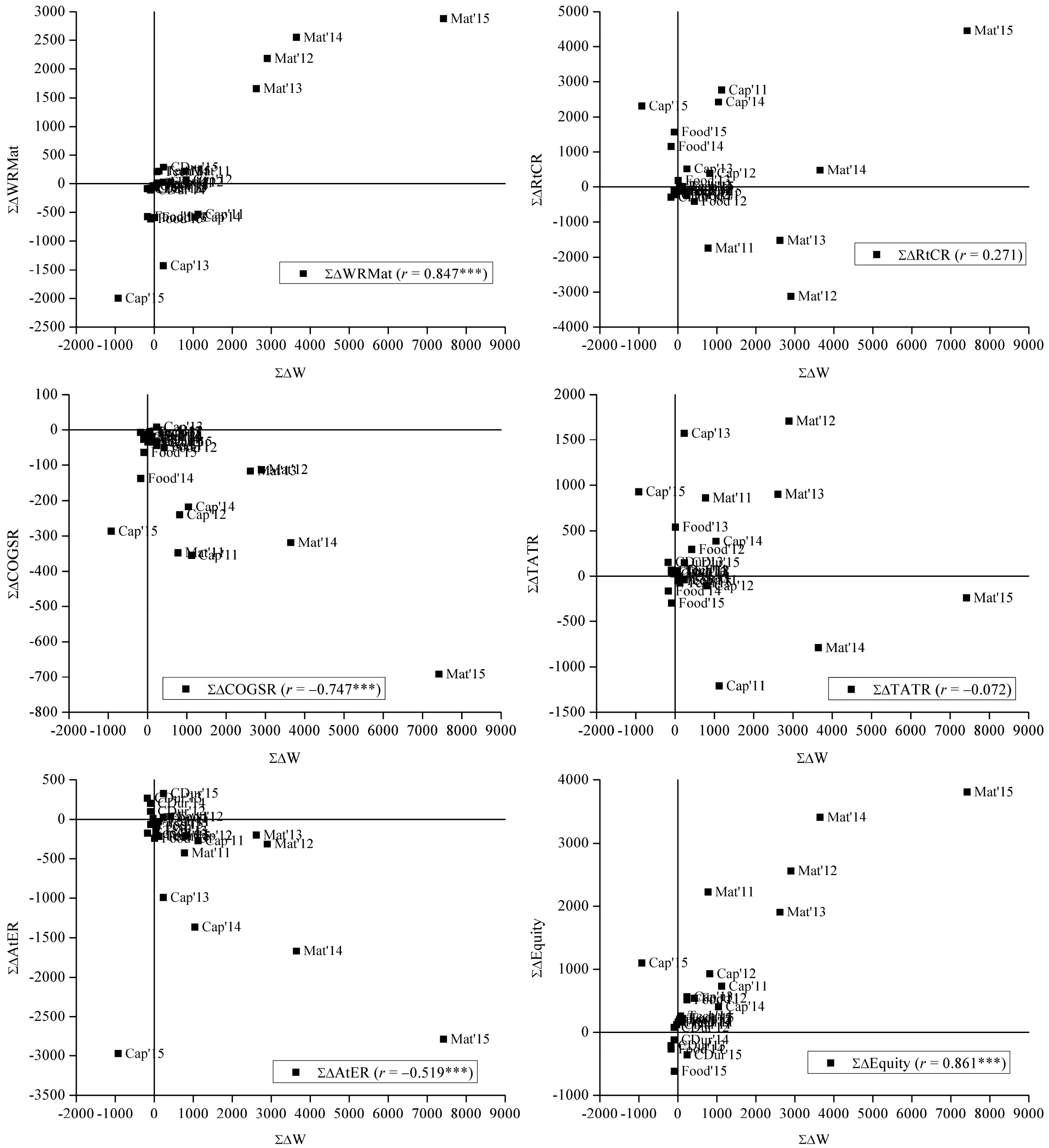

Figure 4. ΣΔW vs. each term of the LMDI for the five sectors, from 2011 to 2015 (25 obs)

Notes: These figures show scatter plots (with sector and year labels) between ΣΔW on the horizontal axis and each term of the LMDI on the vertical axis: upper right for ΣΔWRMat; upper left for ΣΔRtCR; middle left for ΣΔCOGSR; middle right for ΣΔTATR; lower left for ΣΔAtER; and lower right for ΣΔEquity. The sector labels include Mat, Cap, CDur, Food, and Tech, whereas the year labels are ’11, ’12, ’13, ’14, and ’15. The number of observations is 25 for the five sectors from 2011 to 2015. *r* denotes the correlation coefficient, whereas *** denotes statistically significant level of 1%. See Table 5 for the correlation table.

Table 1. MFCA literature, mainly published in the JCLP

Publication	JCLP	Contents	Countries of analysis	Information
Jasch (2003)	✓	Discussion and review	Austria	The introduction of EMA; the pulp and paper company in Austria
Jasch (2006)	✓	Discussion and review	Austria	The introduction of EMA; fictitious, composite brewery in Austria
ISO 14051 (2011)	--	ISO 14051	The Czech Republic, Germany, Japan, the Philippines, and Vietnam	General framework
Nakano and Hirao (2011)	✓	Development models	Japan	LCA and supply chain collaboration model; three case studies (chair production, rubber recycling, and clothes production) in Japan
Bautista-Lazo and Short (2013)	✓	Development models	--	Fit thinking based on the All-Seeing-Eye-of-Business
Fakoya and Van Der Poll (2013)	✓	Development models	South Africa	Enterprise resource planning systems and MFCA; A large brewery in South Africa
Kasemset et al. (2013)	✓	Case studies	Thailand	A textile factory in ChiangMai, Thailand
Nakajima et al. (2013)	✓	Questionnaire surveys	Japan	MFCA questionnaire survey in Japan (received 356 questionnaires) as of 2012
Bierer et al. (2015)	✓	Development models	(Some examples)	A procedure model for the integrated use of life cycle costing and LCA
Chompu-Inwai et al. (2015)	✓	Development models	Thailand	MFCA and Design of Experiments concepts; a small-and-medium-sized enterprise in Thailand; 148 music boxes using ANOVA and estimates the possibility of waste reduction
Christ and Burritt (2015)	✓	Discussion and review	--	A review of MFCA literature; General discussion
Guenther et al. (2015)	✓	Discussion and review	--	A review of MFCA literature
Jasch (2015)	✓	Case studies	(Multiple projects)	About 100 case studies for the UNIDO TEST approach for EMS and MFCA as an initiative of the United Nations
Kokubu and Kitada (2015)	✓	Case studies	Japan	Three companies in Japan: Tanabe Seiyaku, Canon, and Sekisui Chemical
Kurdve et al. (2015)	✓	Development models	Sweden	An integrated waste flow mapping method; two companies (an assembly plant of the Concentric AB and 16 Swedish sites of the Volvo Group)
Rieckhof et al. (2015)	✓	Discussion and review	--	MFCA from the viewpoint of the four levers of control in the field of management control systems
Schaltegger and	✓	Discussion and review	--	A review of MFCA literature; general discussion

Zvezdov (2015)				
Schmidt (2015)	✓	Development models	(Some examples)	A mathematical algorithm for MFCA with two examples (an aluminum rolling mill and an internal material cycle in a production system)
Schmidt et al. (2015)	✓	Development models	(An example)	Extending the scope of MFCA concerning the modeling of energy flow; an example of a specific group of companies (subcontractors processing semi-finished parts in energy-intensive manufacturing steps)
Sulong et al. (2015)	✓	Case studies	Malaysia	Five Malaysian automotive parts companies
Wagner (2015)	✓	Discussion and review	(Several examples)	The historical development of MFCA; several examples
Wan et al. (2015)	✓	Development models	Malaysia	The MFCA-based approach developed for prioritization of waste recovery with consideration of hidden costs embedded in process streams; two case studies (aluminum production system and sago starch extraction process)
Jakrawatana et al. (2016)	✓	Case studies	Thailand	The cassava starch production system (14 plants) and ethanol production (2 plants) in Thailand
Kitada et al. (2016)	--	Questionnaire surveys	Japan	MFCA questionnaire survey in Japan (received 250 questionnaires) as of 2015
ISO 14052 (2017)	--	ISO 14052	(Two examples)	Practical implementation in a supply chain
Mahmoudi et al. (2017)	✓	Case studies	Iran	The wastewater treatment unit of the Tabriz Oil Refining Company, Iran
Zhou et al. (2017)	✓	Development models	China	MFCA modeling; a modified MFCA model for an iron and steel enterprise
Kokubu and Nakajima (2018)	--	Discussion and review	Asia (China, India, Korea, Malaysia, and Vietnam)	A review of MFCA literature; case studies in Asia
Yagi and Kokubu (2018)	✓	Questionnaire surveys	Thailand	Material flow management for non-financial listed companies in Thailand (101 responses) as of 2017

Notes: This table summarizes MFCA studies until 2018, mainly published in the JCLP, in order of publication year and name. A checkmark in the JCLP column denotes JCLP publication. Contents include discussion and review, case studies, development models, questionnaire surveys, and ISO 14051/14052. Countries of analysis are shown for case studies. Information denotes other information on the article contents.

Table 2. Corporate disclosure of total waste and raw materials from 2010 to 2015

GICS	Manufacture ring sectors	Total firms in Bloomberg Database	Corporate disclosure fully from 2010 to 2015				Sample in this study (financial variables are available)
			Total waste		Raw material used		
			Firms	%	Firms	%	
1510	Materials	311	66	21.2%	40	12.9%	38 (39)
2010	Capital Goods	676	84	12.4%	38	5.6%	35 (35)
2510	Automobiles & Components	126	27	21.4%	8	6.3%	-- (7)
2520	Consumer Durables & Apparel	191	23	12.0%	11	5.8%	11 (11)
3020	Food Beverage & Tobacco	139	33	23.7%	24	17.3%	24 (24)
3030	Household & Personal Products	34	7	20.6%	3	8.8%	-- (3)
3520	Pharmaceuticals, Biotechnology & Life Sciences	78	16	20.5%	6	7.7%	-- (6)
4520	Technology Hardware & Equipment	245	48	19.6%	17	6.9%	17 (17)
4530	Semiconductors & Semiconductor Equipment	60	10	16.7%	1	1.7%	-- (1)
	Total	1860	314	16.9%	148	8.0%	125 (143)

Notes: This table is presented in the following order: 1) total active firms; 2) companies that completely disclose the amount of total waste from 2010 to 2015 in item 1; and 3) companies that disclose the entire amount of raw materials used entirely from 2010 to 2015 in item 2. This study excludes one firm in #1510 that presents outliers for the amount of raw material used (the fluctuations within the six observed years were too great).

Table 3. Results of the LMDI: average values of the relative contribution ratio

Columns	1	2	3	4	5	6
Sector	Entire sample	#1510	#2010	#2520	#3020	#4520
|ΔWRMat|/Denom	0.252	0.241	0.257	0.303	0.250	0.239
	(0.178)	(0.184)	(0.189)	(0.167)	(0.172)	(0.154)
|ΔRtCR|/Denom	0.244	0.245	0.220	0.215	0.282	0.256
	(0.150)	(0.149)	(0.135)	(0.151)	(0.138)	(0.182)
|ΔCOGSR|/Denom	0.045	0.038	0.048	0.041	0.043	0.057
	(0.045)	(0.042)	(0.045)	(0.048)	(0.041)	(0.052)
|ΔTATR|/Denom	0.145	0.150	0.161	0.100	0.135	0.142
	(0.112)	(0.112)	(0.127)	(0.084)	(0.108)	(0.094)
|ΔAtER|/Denom	0.114	0.105	0.125	0.139	0.111	0.102
	(0.094)	(0.090)	(0.097)	(0.108)	(0.094)	(0.087)
|ΔEquity|/Denom	0.200	0.220	0.189	0.202	0.178	0.203
	(0.127)	(0.138)	(0.111)	(0.120)	(0.122)	(0.137)

Notes: Values with and without parentheses are average values and their standard deviations, respectively. See Figure 2.

Table 4. Results of the LMDI: change in the amount of total waste from 2010 (kt)

Columns		1	2	3	4	5
Sector	Year	2011	2012	2013	2014	2015
Entire sample (125 firms)	ΣΔW (LHS)	2219.7	4107.2	2735.4	4494.3	6770.2
	ΣΔWRMat	−325.7	2173.6	−512.1	1483.2	772.7
	ΣΔRtCR	650.7	−3501.4	−1122.6	3818.0	8206.6
	ΣΔCOGSR	−788.0	−423.3	−160.9	−724.9	−1114.3
	ΣΔTATR	−377.4	1996.5	3224.1	−557.4	462.5
	ΣΔAtER	−689.0	−468.7	−1309.3	−3211.6	−5709.8
	ΣΔEquity	3749.2	4330.5	2616.2	3687.0	4152.4
#1510 (38 firms)	ΣΔW (LHS)	775.4	2901.6	2621.1	3647.0	7420.2
	ΣΔWRMat	217.5	2184.2	1658.9	2547.0	2879.6
	ΣΔRtCR	−1748.3	−3122.0	−1526.4	474.5	4452.0
	ΣΔCOGSR	−348.4	−113.0	−117.1	−319.4	−692.3
	ΣΔTATR	861.1	1707.0	901.3	−792.0	−239.7
	ΣΔAtER	−426.1	−312.0	−198.1	−1669.5	−2787.4
	ΣΔEquity	2219.5	2557.3	1902.5	3406.3	3808.1
#2010 (35 firms)	ΣΔW (LHS)	1126.1	819.2	235.2	1045.5	−923.5
	ΣΔWRMat	−535.9	63.1	−1425.6	−584.7	−1997.5
	ΣΔRtCR	2766.6	378.9	511.9	2423.1	2307.7
	ΣΔCOGSR	−355.1	−240.9	7.5	−218.3	−286.9
	ΣΔTATR	−1210.8	−107.5	1570.9	384.2	927.5
	ΣΔAtER	−268.1	−204.5	−992.8	−1367.7	−2973.4
	ΣΔEquity	729.4	930.1	563.3	408.7	1099.0
#2520 (11 firms)	ΣΔW (LHS)	−25.7	−96.6	−175.5	−95.3	239.0
	ΣΔWRMat	−40.0	−79.5	−86.7	−109.6	285.0
	ΣΔRtCR	−121.9	−223.8	−291.0	−110.8	−128.0
	ΣΔCOGSR	−20.4	−13.1	−7.4	−28.1	−34.1
	ΣΔTATR	25.0	42.0	153.4	68.3	149.8
	ΣΔAtER	9.3	100.7	268.3	205.1	329.2
	ΣΔEquity	122.2	77.1	−212.1	−120.4	−362.9
#3020 (24 firms)	ΣΔW (LHS)	235.3	422.5	11.6	−172.8	−88.5
	ΣΔWRMat	23.3	24.4	−591.7	−575.3	−613.0
	ΣΔRtCR	−244.1	−417.9	174.1	1150.8	1569.7
	ΣΔCOGSR	−45.3	−51.4	−35.6	−138.5	−64.9
	ΣΔTATR	−42.1	293.0	540.2	−166.1	−298.0
	ΣΔAtER	25.6	34.3	−237.7	−173.0	−64.7
	ΣΔEquity	517.9	540.1	162.3	−270.7	−617.6
#4520 (17 firms)	ΣΔW (LHS)	108.6	60.6	43.0	69.9	123.1
	ΣΔWRMat	9.4	−18.5	−66.9	205.7	218.5
	ΣΔRtCR	−1.7	−116.6	8.9	−119.6	5.3
	ΣΔCOGSR	−18.8	−4.9	−8.4	−20.8	−36.0
	ΣΔTATR	−10.7	62.0	58.3	−51.9	−77.0
	ΣΔAtER	−29.7	−87.2	−149.1	−206.6	−213.5
	ΣΔEquity	160.2	225.8	200.2	263.0	225.8

Note: See Figure 3.

Table 5. Correlation table of each term of the LMDI for the five sectors, from 2011 to 2015 (25 obs)

	ΣΔW	ΣΔWRMat	ΣΔRtCR	ΣΔCOGSR	ΣΔTATR	ΣΔAtER	ΣΔEquity
ΣΔW	(1.000)	--	--	--	--	--	--
ΣΔWRMat	0.847***	(1.000)	--	--	--	--	--
ΣΔRtCR	0.271	−0.169	(1.000)	--	--	--	--
ΣΔCOGSR	−0.747***	−0.422**	−0.579***	(1.000)	--	--	--
ΣΔTATR	−0.072	−0.100	−0.490**	0.217	(1.000)	--	--
ΣΔAtER	−0.519***	−0.139	−0.615***	0.731***	−0.104	(1.000)	--
ΣΔEquity	0.861***	0.748***	0.058	−0.758***	0.130	−0.627***	(1.000)

Notes: This is a correlation table of each term in the LMDI for the five sectors, from 2011 to 2015 (25 observations because of 5 sectors each in 5 years). *** and ** denote statistically significant levels of 1% and 5%, respectively. See Figure 4 for scatter plots between Σ△W and each term of the LMDI.

Table 6. Comparison of the summary results between this study and Yagi and Managi (2018)

Equation 3: 125 Japanese manufacturing firms from 2010 to 2015 in this study	(A1) The relative contribution ratio (sample average) (Table 3)	(B1) LMDI of the entire sample from 2010 to 2015 (kt) (Table 4)	(C1) Correlation coefficient between ΣΔW and each term (25 obs) (Table 5)
ΣΔW	--	6770.2 kt	(1.000)
ΣΔWRMat	25.2%	772.7 kt	0.847***
ΣΔRtCR	24.4%	8206.6 kt	0.271
ΣΔCOGSR	4.5%	−1114.3 kt	−0.747***
ΣΔTATR	14.5%	462.5 kt	−0.072
ΣΔAtER	11.4%	−5709.8 kt	−0.519***
ΣΔEquity	20.0%	4152.4 kt	0.861***
Equation 2: 225 Japanese manufacturing firms from 2011 to 2015 in Yagi and Managi (2018)	(A2) The relative contribution ratio (sample average) (Yagi and Managi, 2018, p.1488, Table 6)	(B2) LMDI of the entire sample from 2011 to 2015 (kt) (Yagi and Managi, 2018, pp.1486-1487, Table 5)	(C2) Correlation coefficient between $\Sigma\Delta CO_2$ and each term (16 sectors as of 2015) (Yagi and Managi, 2018, p.1489, Table 7)
$\Sigma\Delta CO_2$	--	−802.1 kt	(1.000)
$\Sigma\Delta CO_2$Int	20.6%	2922.5 kt	0.226
ΣΔEneInt	19.1%	−26036.3 kt	−0.011
ΣΔCOGSR	25.5%	−6350.5 kt	−0.344
ΣΔTATR	5.5%	−8495.6 kt	−0.431*
ΣΔAtER	13.8%	−7912.3 kt	−0.846***
ΣΔEquity	15.5%	45070.1 kt	0.662***

Note: *** and * denote statistically significant levels of 1% and 10%, respectively.

Appendix Table A1. Descriptive statistics (in the entire sample)

Variables	obs	Average	SD	Min	Max
Waste (W) (kt)	750	279.9	852.3	0.253	9835.0
Material (kt)	750	996.4	2138.2	0.128	18770.0
COGS (Million USD)	750	5076.5	10502.8	38.8	92251.9
Sales (Million USD)	750	6777.1	13998.8	50.4	122503.0
Assets (Million USD)	750	7423.7	17844.3	76.6	160906.1
Equity (Million USD)	750	2879.5	5477.9	30.1	37536.0
WRMat (W / Material)	750	0.265	0.351	0.006	2.831
RtCR (Material / COGS)	750	0.310	0.558	0.000	5.878
COGSR (COGS / Sales)	750	0.763	0.115	0.417	1.050
TATR (Sales / Assets)	750	1.060	0.386	0.231	2.841
AtER (Assets / Equity)	750	2.579	1.970	1.077	44.073

Notes: SD stands for standard deviation. See Supplementary material for the raw dataset of this study.

Appendix Table A2. Aggregate data and corresponding ratios of the entire sample (125 firms) from 2010 to 2015

	1	2	3	4	5	6	7
Year	2010	2011	2012	2013	2014	2015	Total
1) Basic variables							
Waste (kt)	31,604.5	33,824.3	35,711.8	34,340.0	36,098.8	38,374.7	209,954.1
Material (kt)	114,689.0	129,473.9	119,502.1	125,876.8	126,289.8	131,470.1	747,301.6
COGS (Million USD)	594,368.9	649,925.5	705,906.7	676,521.4	607,180.9	573,442.9	3,807,346.2
Sales (Million USD)	785,444.0	877,168.6	939,134.8	894,523.0	816,607.8	769,937.9	5,082,816.2
Assets (Million USD)	886,012.8	994,492.8	1,012,751.5	927,115.7	908,543.1	838,873.6	(5,567,789.6)
Equity (Million USD)	342,423.7	381,242.0	377,388.0	355,693.6	358,641.9	344,250.2	(2,159,639.2)
(Relative rate from 2010)							
Waste	(100%)	107.0%	113.0%	108.7%	114.2%	121.4%	--
Material	(100%)	112.9%	104.2%	109.8%	110.1%	114.6%	--
COGS	(100%)	109.3%	118.8%	113.8%	102.2%	96.5%	--
Sales	(100%)	111.7%	119.6%	113.9%	104.0%	98.0%	--
Assets	(100%)	112.2%	114.3%	104.6%	102.5%	94.7%	--
Equity	(100%)	111.3%	110.2%	103.9%	104.7%	100.5%	--

Appendix Table A3. Aggregate data and corresponding ratios for each industry (in the entire period)

	#1510 (Mat.)	#2010 (Cap.)	#2520 (CDur.)	#3020 (Food.)	#4520 (Tech.)	Total
The number of firms	38	35	11	24	17	125
1) Basic variables (sum of the six years)						
Waste (kt)	88,547.6	80,846.3	6,479.5	27,840.7	6,240.0	209,954.1
Material (kt)	311,963.6	227,484.8	36,530.9	133,693.0	37,629.3	747,301.6
COGS (Million USD)	615,283.1	1,055,135.2	739,224.0	549,176.1	848,527.9	3,807,346.2
Sales (Million USD)	761,547.3	1,290,361.5	935,359.9	829,893.0	1,265,654.5	5,082,816.2
Assets (Million USD)	(853,823.9)	(1,372,016.3)	(1,263,476.9)	(728,627.4)	(1,349,845.1)	(5,567,789.6)
Equity (Million USD)	(400,251.2)	(439,032.6)	(314,922.2)	(351,112.7)	(654,320.5)	(2,159,639.2)

Note: Assets and equity are displayed in aggregate for the entire period (six years).