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Corporate material flow management in Thailand: The way to material flow cost accounting

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Abstract

In recent years, material flow cost accounting (MFCA) has gradually been recognized in Asia by the standardization of ISO 14051 and 14052 and by the project of dissemination undertaken by the Asian Productivity Organization (APO). However, MFCA is still not used across the board. This study analyzes the characteristics of material flow (MF) management to facilitate the expanded use of MFCA. The research framework of this study investigates the degree of MF management and the sequential relationships among financial factors, MF management, and waste performance, based on a questionnaire survey of non-financial listed companies in Thailand. Fifty-eight percent of the respondent firms answer that they are managing MF information (self-rating). Meanwhile, 50%, 49%, 29%, and 24% of the firms actually disclose the amounts of total waste, hazardous waste, raw materials consumed, and recycled waste, respectively. The results of this study show that respondent firms with MF management (self-rating) are more likely to manage/disclose total waste, hazardous waste, and raw materials consumed than those without it. In terms of financial factors, cost ratio and profitability are likely to affect firm decisions regarding whether to manage the MF. Additionally, MF management is likely to decrease the hazardous waste ratio. The series of results shows that firms in Thailand are more likely to be concerned about hazardous waste management than resource efficiency. Therefore, hazardous waste should probably be thoroughly managed, as a preliminary step in the promotion of MFCA.

Keywords: Material flow management; Thailand; Waste performance; Material flow cost accounting; Data envelopment analysis

JEL codes: M11, Q53, Q56

1. Introduction

As the International Organization for Standardization (ISO) has standardized ISO 14051 and 14052 for material flow cost accounting (MFCA) (ISO, 2011, 2017), mechanisms for companies to manage their material flow (MF) have been gradually put in place in recent years. MFCA is an accounting method that directly connects to resource efficiency and can bring cost reduction. Expanding the use of MFCA is an important issue for sustainability, improving resource efficiency at the corporate and even the country level (c.f., Sustainable Consumption and Production [SCP] in Sustainable Development Goals proposed by the United Nations; United Nations Development Program, 2015). In recent years, the Asian Productivity Organization (APO), supported by the Japanese Ministry of Economy, Trade, and Industry (METI), has conducted a project to expand the use of MFCA in Asia (APO, 2012 and 2016). In Thailand, MFCA programs and promotion activities have been conducted mainly at Chiang Mai University, and several case studies are progressing as well (Chompu-Inwai et al., 2015; Kasemset et al., 2013; Jakrawatana et al., 2016). According to two surveys of the Japanese manufacturing industry (Kitada et al., 2016; Nakajima et al., 2013), while MFCA has been gradually spreading, at least in Japan, it is not presently at the stage where it can become popular in Japan and other Asian countries (Kasemset et al., 2013).

For MFCA-promoting policies, it is important to first investigate the company's MF management needs. The reason MFCA is not spreading more rapidly may be attributable to the fact that MFCA is simply underpublicized (e.g., its economic and management merits are unclear or unknown). If the introduction of MFCA is immediately beneficial, however, firms exposed to market competition will soon introduce MFCA to gain superiority over competitors. Thus, this study hypothesizes that firms may have little need or little foundation to introduce MFCA from a management perspective. MFCA usually requires all MF information about a company but often what type of MF information is actually managed and considered important is unknown (e.g., total, hazardous, and recycled waste and raw materials used). Also, the level of management control system (MCS) firms usually have in place as a foundation for MFCA/MF management is often unclear. Thus, this study posits that a better understanding of the needs of companies will help to spread MFCA.

Following the concept of MCS in the MFCA literature, the five-stage MFCA model is proposed by Rieckhof et al. (2015) to improve resource efficiency as an aspect of corporate strategy. By referring to this model, this study presents an analytical framework for examining the current situation of MF management based on a questionnaire survey. The framework first investigates the degree of management of MF information (such as the amount of total waste) and then clarifies the sequential relationships among financial factors, MF management, and waste performance. This study surveys listed companies in Thailand. The reason for choosing Thailand is because Thailand is representative of emerging countries where MFCA is presently known to some extent. Also, its economic ties with Japan are strong (Ministry of Foreign Affairs of Japan [MOFA], 2017) and hence it is relatively easy for APO to promote MFCA in Thailand.

According to the 101 responses from 596 target non-financial firms, 58% of the firms answer that they are managing MF information. This answer refers only to self-rating and does not necessarily indicate the actual situation of MF management. Meanwhile, 50%, 49%, 29%, and 24% of the respondent firms actually disclose the amounts of total waste produced, hazardous waste, raw materials consumed, and recycled waste, respectively. This indicates that firms in Thailand are more likely to be concerned about total waste and hazardous waste than about raw materials and recycled waste.

In terms of analytical results, this study finds that firms with MF information are more likely to disclose the total waste, the hazardous waste, and the raw materials than are those without it. In terms of financial factors, cost ratio (as the operation factor) and profitability affect whether firms choose to manage MF information. Finally, MF management decreases the hazardous waste ratio, among other indicators of waste performance, and the hazardous waste ratio is likely to have the scale of economy.

This paper is organized as follows. Section 2 explains the background of MFCA literature and research in Thailand. Section 3 introduces the material and methods used in this study: the framework of the research, questionnaire survey, research procedure, and financial data. Section 4 shows the results of this study. Finally, Section 5 concludes.

2. MFCA literature and research in Thailand

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, 2011). MFCA was devised as part of environmental management accounting (EMA) and focuses “on a revised calculation of production costs on the basis of material flows” (Jasch, 2003). The history of MFCA starts with a textile company in Southern Germany in the late 1980s (as detailed in Wagner (2015)). Since around 2000, MFCA has been experimentally introduced into certain companies, as it was, for example, introduced by METI into Nitto Denko. Efforts toward a new standardization of MFCA for EMA of the ISO 14000 family began in 2007, leading to the eventual standardization of ISO 14051 (ISO, 2011) and ISO 14052 (ISO, 2017) (Kokubu and Kitada, 2015).

MFCA is an accounting method that seeks to clarify the costs of products and wastes based on MF, aiming at improving resource efficiency (APO, 2014). MFCA is essentially related to cost accounting, covering the cost of goods sold (COGS). In cost calculation, MFCA (ISO 14051) breaks COGS down into four costs: material cost, energy cost, waste management cost, and system cost. These costs are further divided into the costs of positive and negative products, which are an ordinary product and a waste product, respectively. Note that regarding the recycling rate, an increase in the recycling rate in MFCA has little meaning because a series of costs will occur at the time of waste generation. Note also that regarding hazardous waste, MFCA has little to do with whether or not waste is hazardous.

To compile the MFCA literature review, a topic search was conducted in Web of Science (Thomson Reuters’ journal database) with the keyword “material flow cost accounting,” finding 35 journal articles published by 2017. Examining 24 (all published in the *Journal of Cleaner Production*) out of these 35 articles revealed that most of the articles are theoretical (models), case studies, and literature reviews (Guenther et al. (2015) and Wagner (2015) provide detailed information). Among the 24 articles published in the 2000s, Jasch (2003, 2006) discusses MFCA as a component of EMA, raising two case studies: a pulp and paper company and a fictitious composite brewery in Austria. The remaining 22 articles were published from 2011 to the present, once ISO 14051 had been standardized. Bierer et al. (2015), Christ and Burritt (2015), and Schaltegger and Zvezdov (2015) provide a general discussion of MFCA. Additionally, Nakajima et al. (2013) conduct an MFCA survey in Japan. Rieckhof et al. (2015) review MFCA from the viewpoint of the four levers of control (LOC) in the field of MCS (Simons, 1994, 1995).

MFCA development models and their application have been proposed in the following nine articles: life cycle assessment (LCA) and supply chain collaboration model (Nakano and Hirao, 2011); enterprise resource planning systems and MFCA (Fakoya and Van Der Poll, 2013); fit thinking based on the all seeing-eye-of-business (Bautista-Lazo and Short, 2013); a mathematical algorithm for MFCA with two examples (an aluminum rolling mill and an internal material cycle in a production system) (Schmidt, 2015); an integrated waste flow mapping method (Kurdve et al., 2015); a procedural model for the integrated use of life cycle costing and LCA (Bierer et al., 2015); MFCA and design of experiments concepts (Chompu-Inwai et al., 2015); extending the scope of MFCA concerning the modeling of energy flow (Schmidt et al., 2015); a modified MFCA model for an iron and steel enterprise (Zhou et al., 2017); and the prioritization of waste recovery with consideration of hidden costs embedded in process streams (Wan et al., 2015).

Regarding the application of MFCA, the following five articles provide a case study of MFCA: Kasemset et al. (2013) (a textile factory in Thailand); Kokubu and Kitada (2015) (three companies in Japan); Sulong et al. (2015) (a Malaysian automotive parts company); Jakrawatana et al. (2016) (a cassava starch production system and ethanol production in Thailand); and Mahmoudi et al. (2017) (the wastewater treatment unit of the Tabriz Oil Refining Company in Iran). In addition, Jasch (2015) introduces the United Nations Industrial Development Organization (UNIDO) TEST approach, referring to approximately 100 case studies, but publishes only general results (because of confidentiality obligations).

One feature of these MFCA studies is that most focus on an individual firm (case study and model); however, the MFCA literature rarely conducts surveys and empirical analyses comparing companies. This study finds two surveys in Japan as described below, demonstrating that MFCA is not presently popular among Japanese manufacturing firms. Two analyses of the Japanese manufacturing industry, Nakajima et al. (2013) and Kitada et al. (2016), have conducted questionnaire surveys of MFCA implementation. In Nakajima et al. (2013), there were 356 responses from the listed manufacturing firms in Japan in 2012 (1561 firms; response rate: 22.8%). Results show that as of 2012, MFCA was known of by 88 out of 356 firms (24.7%) and had been introduced in 7 firms (2.0%). On the other hand, Kitada et al. (2016) conducted a similar survey in 2015 and received 250 responses. They uniquely divide MFCA implementation into operational and strategic MFCA. They find that 43 of 250 firms (17.2%) answered that they were implementing strategic MFCA. Therefore, these two studies show that firms with MFCA are steadily increasing but have not yet spread across the board.

In recent years, APO has conducted a project to expand the use of MFCA in Asia through e-learning, workshops, demonstrations, training courses, etc. (APO, 2012 and 2016). The MFCA project, mainly led by APO, started in 2010, and e-learning courses were held in 2011 and 2012, with 225 participants from 10 countries, including Thailand. As an example of what has been done in other ASEAN countries, the Vietnam Productivity Center introduced MFCA to three small and medium-sized enterprises in Vietnam in 2011 through workshops hosted by the APO, with others. The participants increased to 25 firms in 2015 and 40 firms in 2017, as expected (Kokubu and Nakajima, 2018).

In Thailand, MFCA programs and promotion activities have been conducted mainly at Chiang Mai University (Chompu-Inwai et al., 2015; Kasemset et al., 2013). APO also conducted a pilot project, including MFCA, in Thailand from 2013 to 2015 (APO, 2016). This study finds three journal articles in the below about MFCA research in Thailand. Kasemset et al. (2013) apply MFCA to a small textile factory as a case study. Its cost percentages of positive and negative products were found to be approximately 84% and 16%, respectively. Similarly, Chompu-Inwai et al. (2015) apply MFCA to a wood-product manufacturing company. The cost percentages of positive and negative products were approximately 30% and 70%, respectively. Jakrawatana et al. (2016) analyze the starch and ethanol production of cassava processing. They find that, in terms of starch production, the material losses in business as usual (BAU) are 6±4% in washing/rasping, 49±11% in extraction/separation, and 48±13% in dewatering/drying. In terms of the ethanol production, similarly, the material losses in BAU are 59.5±2% in (chipping + sundry) + grinding/slurry and 94±40% in distillation/dehydration.

Thus, Thailand is representative of emerging countries in Asia where MFCA is presently known to some extent. Also, it is relatively easy for APO to have a project for promoting MFCA in Thailand because its economic ties with Japan are strong. For Thailand, Japan is the largest investor and accounts for 22% of total foreign direct investment (79.6 billion Thai Baht [THB] in 2016); the number of member companies of the Japan Chamber of Commerce and Industry (JCCI) in Bangkok is 1,701, as of February 2016 (MOFA, 2017). Recently, economic growth in Thailand has been slowing, probably because of high geopolitical risks (the flood in 2011 and political issues) (Haraguchi and Lall, 2015; Singkran, 2017). In general, MFCA has not thus far been used in Thailand (Kasemset et al., 2013). In order to fully promote MFCA, it is important to first investigate the needs of MF management from the company's perspective. Therefore, this study investigates the current status of MF management in Thailand through a questionnaire survey.

3. Material and Methods

3.1 Research perspective based on the five-stage MFCA model

Most of the extant MFCA literature focuses on individual studies (case studies and models) but often does not conduct actual surveys or empirical studies. More specifically, in Thailand, MFCA has gained gradual recognition but is still not presently popular among listed firms. Based on this background, this study aims to examine the primary research question of how MFCA can become more widely used through a questionnaire survey. The research framework of this study employs the model of Rieckhof et al. (2015), as explained below. Note that Rieckhof et al. (2015) conducted a theoretical review and not an actual investigation. Therefore, the survey from this study will contribute to the work of Rieckhof et al. (2015) by providing supportive empirical evidence. However, in conducting the questionnaire survey, it is difficult for firms to answer detailed academic questions. Therefore, this study investigates MF management in general.

Rieckhof et al. (2015) propose a five-stage model (enabling, integrating, communicating, flow-thinking, and learning) for integrating MFCA into part of a corporate strategy, with the aim of improving resource efficiency and sustainable development. The enabling stage (1st stage) examines the cost in deciding whether to introduce MFCA. It chooses cost types, considers costs adequately, and applies causal allocation principles. The integrating stage (2nd stage) addresses operational issues, linking MFCA to the information system and traditional cost accounting and deriving indicators for performance measurement. In the communicating stage (3rd stage), it becomes important to communicate both within (communicating across departments) and outside (enhancing reporting) the company. The flow-thinking stage (4th stage) seeks integrative flow management, while the learning stage (5th stage) aims to finally create the firm as a learning organization.

MCS can be clustered into four LOC used by managers: beliefs system (defining, communicating, and reinforcing the basic values, purpose, and direction for the organization), boundary system (establishing explicit limits and rules), diagnostic control system (monitoring organizational outcomes and correcting deviations from preset standards of performance), and interactive control system (regularly and personally involving top managers in the decision activities of subordinates) (Simons, 1994, 1995). In particular, the diagnostic and interactive control systems among the four LOC are important in the 1st stage and part of 2nd, and 3rd stages (i.e., integrating MFCA with traditional cost accounting and enhancing reporting), and all four LOC are important in the remaining 2nd and 3rd stages (i.e., deriving indicators for performance measurement and communicating across departments) and the 4th and 5th stages.

Before following Rieckhof et al. (2015), this study directly asks whether MF management is conducted. This is the simplest question and can roughly capture the trend of MF management. One aspect of this question is that it is only self-rating. Therefore, based on this self-rating of MF management, this study creates a three-step research framework to determine the kinds of MF management being used, following Rieckhof et al. (2015) as described below.

Regarding the enabling stage (the 1st stage), this study examines what types of cost structure (financial factors) will affect MF management. Because a detailed cost structure is often unavailable due to the confidential nature of the information, this study investigates how financial factors in general work on MF management (through regression analysis).

Regarding the integrating and communicating stages (the 2nd and 3rd stages), this study first investigates the relationship between information system/reporting and MF management. If firms manage MF, the basic MF information (e.g., the amounts of waste, hazardous waste, the raw material used, and recycled waste) should be recorded using a firm's information system and can be disclosed to outside parties (although some firms may not disclose the MF information because it may be confidential). In deriving indicators for performance measurement (in the 2nd stage), this study analyzes the relationship between MF management and self-rating environmental performance (e.g., resource efficiency and total and hazardous waste). If MF management is tied to internal performance measurements, certain correlations between them are considered to be shown (positively or negatively). Another important issue of MFCA/MF management is that it requires communication across departments (in the 3rd stage) (e.g., purchase, process, sales, and research and development [R&D] departments). In particular, hypothesizing that more advanced firms are more likely to carry out MFCA/MF management by communicating with the R&D department, this study verifies whether general and environmental R&D activities affect the implementation of MFCA/MF management.

MFCA/MF management is developed as high-level MCS such as the flow-thinking and learning stages (the 4th and 5th stages) but this study does not verify these high levels. We have conducted a pretest (in August 2017) and find that it is likely to be difficult for firms in developing countries to answer complicated questionnaire items.

Finally, MFCA/MF management can be used to improve resource efficiency as an aspect of corporate strategy. Here we confirm whether MFCA/MF management improves objective resource efficiency (e.g., material loss, hazardous waste rate, recycling rate, overall resource efficiency, etc.).

This analysis examines whether MF management is used as a corporate strategy (for resource efficiency).

3.2 Research framework

Following the above research perspective, this study analyzes MF management in Thailand. The focus is the following three steps: 1) the degree of MF information management; 2) the financial determinants of MF management; and 3) the impacts of MF management on actual waste performance. Figure 1 shows the research framework of this study.

Regarding step 1, this study investigates the actual state of MF management. We separate self-rating questions and actual management of MF information. Table 1 shows the 12 questionnaire items in this study. The question about self-rating MF management (Q1) asks whether or not companies manage MF information (answers: yes or no). The questions about objective assessment ask firms to disclose the total amounts of the following four items in the latest year: total waste produced (Q2), hazardous waste produced (Q3), raw materials consumed (Q4), and recycled waste (Q5) (answers: the number of metric tons or n/a). By comparing Q1 and Q2-Q5, it is possible to confirm how much of a divergence exists between self-rating and actual management. This serves to verify the integrating and communicating stages (the 2nd and 3rd stages) of the model (Rieckhof et al., 2015) as noted above. Note, however, that a limitation of this study is that there may be firms that do not want to disclose their confidential information to outside parties. An additional limitation of this study is that it cannot verify whether the disclosed values are correct.

As with other self-rating indexes, this study also asks about the strength of a company's environmental performance when compared to that of other companies: this includes resource efficiency (Q10), the efficiency of waste produced (Q11), and the efficiency of hazardous waste produced (Q12). These questions are asked using a Likert scale (1 to 5 (better)). Thus, we can judge how important MF management is by comparing the self-rating MF management (Q1) and these self-rating performance indexes (Q10-Q12).

Regarding step 2, from the viewpoint of MFCA, this study considers MF management to be closely related to financial factors. This verifies the enabling stage (the 1st stage) of the model (Rieckhof et al., 2015) as noted above. This is because raw materials are brought from suppliers, processed in operation, and made into the positive and negative products. The positive products are sold to customers (in the product markets) and the negative products (waste) are dealt with accordingly outside the firms. Furthermore, funds (generally from financial and stock markets) are necessary for these corporate activities. Thus, this study hypothesizes that financial factors may affect the MF management.

This study considers the following 7 financial items: COGS ratio (COGSR; COGS divided by revenue), total asset turnover ratio (TATR; revenue divided by assets), leverage (total assets divided by total equity), lnEquity (total equity in logarithm-form), return on assets (ROA; earnings before interest and tax [EBIT] divided by total assets), R&D ratio (RDR; R&D expenses divided by revenue [%]), and environmental R&D ratio (EnvRDR; environmental R&D expenses divided by total R&D expenses [%]).

The first five indicators (COGSR, TATR, leverage, lnEquity, and ROA) are taken from the financial data. COGSR is a proxy for the cost ratio and hence can be interpreted as an operation factor, because the MF information is essentially handled in the first place in operations. TATR is a proxy for the turnover ratio and can be interpreted as customer pressure: the greater the sales (the numerator), the more firms tend to be in contact with larger markets (potentially facing more powerful customers). Thus, customers in the supply chain may require more stringent environmental management including MF management. Leverage can be interpreted as a proxy for financial market pressure. This is because firms with high leverage may be more conscious of risk management, including MF management, due to the need for additional evaluation from the financial markets. lnEquity is a proxy for firm size, based on the hypothesis that economies of scale may work for MF management. ROA is a proxy for profitability, based on the hypothesis that companies with more of a margin are more likely to adopt MF management. The remaining two items, RDR and EnvRDR, are proxies for general and environmental progressiveness, respectively, hypothesizing that MF management becomes more important in advanced activities such as R&D. Such activities are often not actively disclosed in developing countries; therefore, this study asks directly about R&D expenses (Q6 and Q7) and the environmental R&D percentage (Q8 and Q9). As with Q1 to Q5, Q6 and Q8 are self-rating questions about whether companies conduct R&D and environmental R&D, respectively. Meanwhile, Q7 and Q9 ask companies to disclose the actual R&D expenses and EnvRDR.

Regarding step 3, this study analyzes how MF management affects actual waste performance. This serves to verify whether MF management is used as high-level MCS (the flow-thinking and learning stages [the 4th and 5th stages]) to improve resource efficiency as part of corporate strategy in Rieckhof et al. (2015) as noted above. This analysis is based on the hypothesis that if MF management is done appropriately, it may lead to some improvement in waste performance. This study checks the following four indexes: waste per raw materials (WasteR), hazardous waste ratio (hazardous waste divided by total waste [HazR]), recycled waste ratio (recycled waste divided by total waste [RecR]), and the data envelopment analysis (DEA) score for total waste efficiency (see Supplementary material).

WasteR is the waste ratio of raw materials (material loss), and is the most important value in MFCA, indicating the proportion of negative products. This value usually takes 0-100% (the lower, the better) and may exceed 100%, depending on outliers of the year. HazR is the proportion of hazardous waste (0-100%; the lower, the better). The management of hazardous waste may be more important than waste efficiency in developing countries. This is because hazardous waste may lead to local pollution and accidents. RecR is the percentage of recycling (0-100%; the higher, the better). Usually, the recycling rate is considered important for approaching the zero-emission process (in a narrow sense, within a company).

These three ratios do not take into consideration the company's financial factors. Given the idea of MFCA, it would be more appropriate to estimate overall waste efficiency by considering financial factors. Therefore, this study estimates overall waste efficiency by using a non-parametric productivity indicator in the form of DEA. This study adopts Kuosmanen weak disposability technology under variable returns to scale (VRS), as in Kuosmanen and Kazemi Matin (2011) (see

Supplementary material). The model in this study estimates the productivity indicator that maximizes sales (a desirable output) and minimizes total waste (an undesirable output) at the same time, given COGS and total assets as the two inputs. The DEA score takes a value from 0 (efficient) to 1 (inefficient), indicating by what percentage sales can be increased while waste is being reduced (note that this study estimates the DEA score using all observed firms as the common decision-making units [DMUs]).

Step 3 uses regression analysis to examine whether MF management (Q1, self-rating) and the scale factor (the amount of waste from Q2) improve waste performance (WasteR, HazR, RecR, and DEA score). This analysis is based on the hypothesis that there may be some improvement if certain firms in Thailand manage MF information (Q1) properly. This study also hypothesizes that the waste amount may be important for waste performance (due to the scale of economy).

3.3 Questionnaire survey in Thailand

This study conducts a questionnaire survey by mailing to listed firms in Thailand (it was conducted as part of the survey of the SCP project in Thailand). The survey targets non-financial sectors. Note that the survey has been translated from English into Thai (the local language). Before conducting the questionnaire survey, this study created a list of companies to be surveyed, based on the List of Stock Exchange of Thailand Listed Companies & Contact Information from the website of the Stock Exchange of Thailand.[1] As of August 9, 2017, there were 596 non-financial firms among 663 active listed firms in Thailand. The stock market in Thailand is largely divided into two exchanges, the Stock Exchange of Thailand (SET) and the Market for alternative investment (Mai). Thus, the 596 target firms can be divided into 466 SET firms and 130 Mai firms. Also, the non-financial sectors can be divided into the following 7 sectors: agro & food (59 firms), consumer products (50 firms), industrials (124 firms), property & construction (112 firms), resources (60 firms), services (143 firms), and technology (48 firms). Table 2 shows the response rates. We have conducted the pretest for 11 selected firms in August 2017 and modified the question items based on the pretest result so that firms

[1] Retrieved from https://www.set.or.th/en/company/companylist.html [accessed Feb. 2018]

can respond easily. This study sent questionnaires to all 596 firms between the 1st and 20th October, 2017 and followed up with phone calls made between the 15th and 22nd November, 2017. It received 101 responses, mostly by 30th November, 2017 (response rate: 16.9%).

Regarding the total 101 responses, the numbers of corporate departments that answered the questionnaire are as follows: 37 departments of safety, health, and environment (or security), 8 departments of corporate social responsibility (or sustainability management), 23 departments of human resources (or human development resources), 14 departments of miscellaneous production (quality or control; waste; production; operation; engineering; factory; miscellaneous engineer or scientist), 2 departments of logistics (logistics; packaging), 11 departments of general affairs and accounting (business [general]; accounting; investor relations; audit; secretary; building and location), and 6 anonymous departments (no information). Similarly, the numbers of positions which answered the questionnaire are as follows: 1 chief executive officer, 3 director (or head) levels, 11 manager (or vice manager) levels, and 86 anonymous positions (no information). Note that among the 101 respondents, the names of those who answered the questionnaire are disclosed for 96 respondents and are not disclosed for 5 respondents (anonymous).

3.4 Research procedure (steps 0 to 3)

The research strategy of this study consists of the following four steps (see Figure 1). Step 0 is a check for sample selection. Step 1 is a comparison of the self-rating for MF management (Q1) and the other management items (Q2 to Q12). Step 2 is a regression analysis to determine whether financial factors influence MF management. Step 3 is a regression analysis to determine whether MF management affects waste performance.

In step 0 (as a preliminary), this study targeted the 596 non-financial firms in Thailand and received 101 responses; therefore, there are 495 censored and 101 uncensored observations. If there is a difference between these two groups, sample selection bias may occur. This study first performs a t-test to see whether there is a difference between the averages of the two groups in terms of the following five financial items: revenue, COGS (as a cost), EBIT (as a profit), total assets, and total equity.

Step 1 compares the self-rating for MF management (Q1) and the other management items (Q2 to Q12) to clarify the characteristics of the self-rating for MF management. This study first compares the self-rating (Q1) and the actual MF disclosure (total waste, hazardous waste, raw materials consumed, and recycled waste, from Q2 to Q5) through chi-squared tests using two-by-two tables. If there is a statistically significant and positive difference, it indicates that firms implementing MF management tend to actually manage/disclose the corresponding MF.

Step 2 tests whether the financial factors affect MF management by conducting a regression analysis. It considers 5 objective variables, namely DumQ1 to DumQ5, which correspond to each of Q1-Q5. DumQ1 to DumQ5 are all dummy variables taking a value of either 0 or 1. DumQ1 takes 1 if Q1 (about MF management) is yes and 0 if not. DumQ2, DumQ3, DumQ4, and DumQ5 take 1 if total waste (Q2), hazardous waste (Q3), raw materials consumed (Q4), and recycled waste (Q5) are disclosed, respectively, and 0 if not (i.e., n/a or no answer). Let probability p be the probability that each of DumQ1 to DumQ5 takes 1:

$$p = \begin{cases} \Pr\left(DumQ1 = 1\right) \\ \Pr\left(DumQ2 = 1\right) \\ \Pr\left(DumQ3 = 1\right). \\ \Pr\left(DumQ4 = 1\right) \\ \Pr\left(DumQ5 = 1\right) \end{cases} \tag{1}$$

Setting the logarithm-form of the odds ratio of p as the objective variable, the logistic regression model (using the maximum likelihood estimation) is formulated as follows:

$$\begin{aligned} \ln\left[p/(1-p)\right] = \beta_0 + \beta_1 COGSR + \beta_2 TATR + \beta_3 Leverage + \beta_4 \ln Equity \\ + \beta_5 ROA + \beta_6 RDR + \beta_7 EnvRDR + \beta_8 DumMai + \sum_k \gamma_k DumSector_k \end{aligned} . \tag{2}$$

Note that RDR and EnvRDR will be 0 (%) when there is no answer in the questionnaire survey (Q7 and Q9), because R&D activities are often less than popular in Thailand. DumMai is a market dummy for Mai, controlling for the effect of market heterogeneity. $DumSector_k$ is the dummy variable for the k-th sector, setting the technology sector (which has the fewest observations [obs]) as the base among the seven total sectors.

Step 2 also analyzes whether financial factors increase the amount of waste itself. Because waste emission is based on corporate activity, this study expects that it may be affected by financial factors. Data comes from the amount of waste that was disclosed in Q2; therefore, the set of observations (50 obs in total) has missing values. Note that because it examines waste-emitting firms, this study excludes one company that answered 0 tons in Q2. The regression model is expressed by the following ordinary least squares (OLS) regression, using the same independent variables as in Equation 2:

$$\begin{aligned}\ln Waste = {} & \beta_0 + \beta_1 COGSR + \beta_2 TATR + \beta_3 Leverage + \beta_4 \ln Equity \\ & + \beta_5 ROA + \beta_6 RDR + \beta_7 EnvRDR + \beta_8 DumMai + \sum_k \gamma_k DumSector_k + \varepsilon \end{aligned} \quad (3)$$

lnWaste denotes the total amount of waste produced, in logarithm-form. ε denotes an error term.

Step 3 examines whether MF management (Q1; DumQ1) affects corporate waste performance: WasteR (from Q2 and Q4), HazR (from Q2 and Q3), RecR (from Q2 and Q5), and DEA score (from Q2). Also, this step tests the scale of economy in terms of the amount of total waste (lnWaste from Q2). The regression model is expressed by the following OLS regression:

$$\left.\begin{matrix} WasteR \\ HazR \\ RecR \\ DEA\ score \end{matrix}\right\} = \beta_0 + \beta_1 DumQ1 + \beta_2 \ln Waste + \beta_3 DumMai + \sum_k \gamma_k DumSector_k + \varepsilon . \quad (4)$$

DumQ1 (as in Equations 1) is a dummy variable representing MF management (1: yes, 0: no or no answer). ε denotes an error term. Note that the waste performance indexes are based on the questionnaire survey and therefore that the number of observations is lower than the 101 responses: 26, 45, 20, and 50 observations for WasteR, HazR, RecR, and DEA score, respectively.

3.5 Data

The financial data used in this study comes from the Bloomberg Professional Service. This study uses the financial data for 2016 because little data is available for 2017, as of February 2018.

The currency is the US dollar (USD) (the rate of disclosure date). In calculating the R&D ratio (RDR), this study uses the official exchange rate on period average in 2016: 35.30 THB/USD (obtained from the Worldbank database)[2]. Because of missing values in the financial data, figures are available for only 99 of the total 101 respondent firms.

Regarding the process of creating the dataset, this study directly uses each variable (questionnaire items and financial variables) in each of the statistical analyses (the chi-squared test, t-test, OLS, and the logistic regression model). That is, it uses each questionnaire item directly but does not calculate/conduct scale score measures for multi-item scales (e.g., the mean or sum of items) and the corresponding reliability tests (e.g., Cronbach's coefficient alpha, parallel test, tau-equivalent test, and congeneric test). Because poor reliability with scale score measures may lead to inflated standard errors and/or biased estimates (Biemer et al., 2009), certain reliability tests are often conducted, particularly in the field of psychology, to determine whether a scale score measurement has internal consistency among those question items. However, this study does not adopt the scale score measures and these reliability tests.

4. Results

4.1 Check for sample selection bias (step 0)

Table 3 shows the results of the t-tests for sample selection bias as step 0. In terms of the 5 financial items, this table shows the averages and standard deviations for censored and uncensored firms, the difference between the averages, and the results of the t-test. As a result, t-values are 1.042, 0.967, 1.028, 0.973, and 0.770 for revenue, COGS, EBIT, total assets, and total equity, respectively; hence, all values are not statistically significant. This step thus shows that, at least for these financial elements, there is no sample selection bias.

4.2 Answers from the questionnaire survey

[2] https://data.worldbank.org/indicator/PA.NUS.FCRF [accessed Feb. 2018]

Tables 4 and 5 show the survey results from Q1 to Q9 and Q10 to Q12, respectively. In Table 4, 59 firms (58%) answer yes to whether they manage MF information (Q1). Meanwhile, the numbers of firms which disclose the actual values are 51 (50%) for total waste (Q2), 49 (49%) for hazardous waste (Q3), 29 (29%) for raw materials consumed (Q4), and 24 (24%) for recycled waste (Q5). From these answers, information about total waste and hazardous waste is relatively easy to disclose/manage, while that for raw materials and recycled waste is not.

Regarding Q6 to Q9, 41 and 23 firms (41% and 23%) reported that they conduct general (Q6) and environmental (Q8) R&D activities, respectively. When asking for the actual value, 25 firms (25%) provide the R&D expense (Q7), whereas 13 firms (13%) provide the percentage of the environmental R&D (Q9). Thus, there is a gap between self-rating R&D implementation (Q6 and Q8) and actual disclosure (Q7 and Q9).

In Table 5, the modes of the resource efficiency (Q10), the efficiency of waste produced (Q11) and the efficiency of hazardous waste produced (Q12) are 3 (42 firms), 4 (41 firms), and 4 (40 firms), respectively. The average values are 3.608, 3.566, 3.582, respectively. This implies that on average, these three efficiencies are similar to each other.

4.3 Chi-squared test and t-test (step 1)

In step 1, Tables 6 and 7 show the results of the chi-squared test for Q2 to Q9 and the t-test for Q10 to Q12, respectively. Table 6 consists of multiple two-by-two tables from Q2 to Q9, comparing Q1. The columns of Table 6 divide the number of responses based on whether they are yes or no (or no answer) for MF management (Q1). Similarly, the rows of the table divide the number of responses based on values disclosed or n/a (or no answer) for Q2, Q3, Q4, Q5, Q7, and Q9 and based on whether they are yes or no (or no answer) for Q6 and Q8.

As a result, the chi-squared statistics are estimated as follows: 8.471 for total waste (Q2); 8.878 for hazardous waste (Q3); 3.281 for raw materials (Q4); 0.882 for recycled waste (Q5); 4.310 for R&D activity (self-rating, Q6); 0.567 for R&D expenses (Q7); 0.567 for environmental R&D activity (self-rating, Q8); and 0.924 for environmental R&D percentage (Q9). Given the degree of freedom of 1, the statistically significant differences are found in total waste (Q2), hazardous waste (Q3), raw materials consumed (Q4), and R&D activity (Q6). This indicates that firms with self-rating MF management are more likely to manage these 4 items than those without it.

Table 7 shows the results of the t-test, examining whether the firms with MF management (Q1) believe they are more efficient than those without it. Regarding resource efficiency (Q10), total waste production (Q11), and hazardous waste production (Q12), the average values are 3.679, 3.649, and 3.679 for the firms with MF management and 3.538, 3.475, and 3.475 for the firms without it, respectively. T-values are −0.775, −0.950, and −1.078 for Q10, Q11, and Q12, respectively, indicating that there is no statistically significant difference between the firms with and without MF management (Q1).

4.4 Regression model: financial factors and MF management (step 2)

Table 8 shows descriptive statistics for regression analyses in steps 2 and 3. The number of observations is 99 for DumQ1 to DumQ5, the financial variables and dummy variables (e.g., DumMai), because of two missing values for the financial variables among the 101 respondent firms. Note that the maximum value of RecR is 1 (100%), which excludes an outlier (160,965%).

Table 9 shows the result of the logistic regression model for DumQ1 to DumQ5 (columns 1 to 5, respectively). The coefficient of COGSR is statistically significantly positive for DumQ1 and DumQ3 (columns 1 and 3). This indicates that the operation factor encourages MF management (Q1) and improves the disclosure of hazardous waste (Q3). The coefficient of TATR is statistically significantly negative for DumQ3 (column3). This means that customer pressure discourages corporate disclosure of hazardous waste. The coefficient of ROA is statistically significantly positive for DumQ1 and DumQ3 (columns 1 and 3). This indicates that business margin (profitability) promotes MF management and improves the disclosure of hazardous waste. In addition, leverage, lnEquity, RDR, and EnvRDR are not statistically significant.

Table 9 also shows the results of regression analysis which tests whether financial factors cause an increase in total waste. Column 6 does not consider the dummy variables of market and sector, whereas column 7 does. The coefficient of lnEquity is statistically significantly positive for lnWaste in both columns 6 and 7. As is intuitive, this shows that firm size is related to an increase in waste. The coefficient of EnvRDR is statistically significantly negative for lnWaste in column 7. This indicates that firms with a higher percentage of environmental R&D have a lower amount of waste.

4.5 Regression model: MF management and waste performance (step 3)

Table 10 first confirms the four indexes of waste performance for each market and industry. In terms of the figures for each stock market, average values of WasteR, HazR, RecR, and DEA score are 0.314, 0.227, 0.480, and 0.342 in SET and 0.276, 0.222, 0.042, and 0.496 in Mai, respectively. At least on average, therefore, WasteR and HazR tend to better in Mai, and RecR and DEA score tend to be better in SET. In terms of each industry, the most efficient sectors are the resources sector for WasteR (0.079, 4 obs), the agro & food sector for HazR (average 0.003, 1 obs) and RecR (0.954, 1 obs), and the technology sector for DEA score (0.080, 2 obs). We find the resources sector has the second most efficient values, on average, for HazR (0.183, 6 obs), RecR (0.489, 3 obs), and DEA score (0.160, 6 obs).

Table 11 shows the results of regression analysis for the following four indexes of waste performance: WasteR (columns 1 and 2), HazR (columns 3 and 4), RecR (columns 5 and 6), and DEA score (columns 7 and 8). Columns 1, 3, 5, and 7 do not consider the dummy variables of market and sector, whereas columns 2, 4, 6, and 8 do. The coefficients of DumQ1 (dummy for the MF management) and lnWaste are statistically significantly negative for HazR (columns 3 and 4). This indicates that MF management tends to have a decreasing effect on (i.e., improves) hazardous waste ratio. The larger the scale (lnWaste), the lower the hazardous waste ratio (i.e., the scale of economy works). In addition, MF management and lnWaste have no significant effect on WasteR, RecR, and DEA score (columns 1, 2, 5, 6, 7, and 8).

4.6 Discussion of the results

This study summarizes the results and the implications to the literature as follows. It first shows 58% of the respondent firms confirmed that they are managing MF information, and this rate appears much higher than the rates at which Japanese firms conduct MFCA (2% in Nakajima et al. (2013) and 17.2% in Kitada et al. (2016)). This indicates that MF management itself is much more widely used than MFCA.

Regarding the enabling stage (the 1st stage) of Rieckhof et al. (2015), this study (step 2) reveals that the cost ratio and profitability affect a firm's decision to implement MF management. Therefore, MF management in Thailand is likely to reach the enabling stage.

Regarding the integrating and communicating stages (the 2nd and 3rd stages) of Rieckhof et al. (2015), this study (step 1) shows that MF management (Q1) is positively correlated to the disclosure of total waste produced (Q2), hazardous waste produced (Q3), and raw materials consumed (Q4). This indicates that MF management in Thailand tends to be integrated with the information system, thereby enhancing reporting in terms of total waste, hazardous waste, and raw materials. Meanwhile, MF management (Q1) is positively correlated to self-rating general R&D activity (Q6), but is not statistically correlated to the other R&D activities (Q7 to Q9). In addition, MF management (Q1) is not statistically correlated to the self-rating performance measurement (Q10 to Q12). This indicates that MF management in Thailand is not likely to reach the level of communication across departments (in particular, communication with the R&D/technology department) and the level of deriving (internal) indicators for performance measurement. In other words, it implies that MF management in Thailand employs the diagnostic and interactive control systems among the four LOC but does not tend to utilize the beliefs and boundary systems in the integrating and communicating stages. As to the limitations, this study does not verify the flow-thinking and learning stages (the 4th and 5th stages) as described above.

Regarding objective resource efficiency (as an aspect of corporate strategy), this study (step 3) demonstrates that MF management (Q1) decreases the hazardous waste rate but has no effect on other waste performance measures. This indicates that MF management is not likely to be used to improve resource efficiency (as the corporate strategy) with the exception of the hazardous waste rate.

5. Conclusions

This study analyzes the characteristics of MF management in order to expand the use of MFCA and proposes an analytical framework linking the financial factors, MF management, and waste performance. It surveys the listed non-financial firms in Thailand and applies the analytical framework to the 101 respondent firms.

Figure 2 summarizes the results of the statistical analysis. The estimated results for step 1 indicate that MF management (self-rating) encourages the disclosure of total waste, hazardous waste, and raw materials consumed. The results for step 2 show that operational factors (COGSR), profitability (ROA), and customer pressure (TATR only for hazardous waste) are likely to affect MF management and the disclosure of hazardous waste. The results for step 3 indicate MF management is likely to improve (decrease) the hazardous waste ratio.

The results show that MF management in Thailand is probably best employed for waste management, and in particular for hazardous waste management. The implication for industrial policy in Thailand is that corporate MF management should take steps to adopt MFCA. Hazardous waste should probably be thoroughly managed, as a preliminary step in the promotion of MFCA. Following this, it would likely be more effective to then promote MFCA as a next step. If hazardous waste is not firmly managed, there is a high risk that other materials will also not be well managed. The results of this study (step 2) suggest there is a possibility that the supply chain management, including the operation factors (inside the company) and customer pressure (outside the company) can encourage hazardous waste management; therefore, supply-chain management will play an important role in the management of hazardous waste. Once a particular firm establishes an information management system for hazardous waste, other materials are likely to be managed as well due to the scope of economy. In particular, the management of material loss (the raw materials) is not much practiced and should be strongly promoted. This is because MFCA is a tool for material loss and productivity improvement, as in the efforts of the Vietnam Productivity Center (Kokubu and Nakajima, 2018). Thus, this study argues that the best way to spread MFCA will be seen after firmly promoting hazardous waste and raw material management.

The implication for the extant literature is that MF management in Thailand appears to partially reach the enabling, integrating, and communicating stages of Rieckhof et al. (2015). Meanwhile, it seems to lack in deriving indicators for performance measurement and communicating across departments (part of 2nd and 3rd stages). In other words, it appears deficient in terms of its extended focuses on all four LOC, including not only diagnostic and interactive control systems, but also beliefs and boundary systems. In addition, it does not to lead to improvements in resource efficiency as part of a corporate strategy (with the exception of the hazardous waste rate). In this way, MF management in Thailand appears to have the potential to develop to a higher stage beyond its present position.

In terms of the limitations of this study, it does not verify detailed academic issues about MCS for MF management (such as the flow-thinking and learning stages) because they are likely to be difficult for firms to answer (particularly in developing countries including Thailand). Therefore, the questionnaire items and research framework have room for improvement. As a matter of course, it is essential to investigate not only Japan and Thailand, but also other countries, in order to ensure the robustness of the findings. Also, importantly, this study does not explore specific policy discussions about how to make use of the findings from the this study in concrete terms. These remaining issues are not addressed in this study but they are expected to be gradually resolved as additional survey results accumulate.

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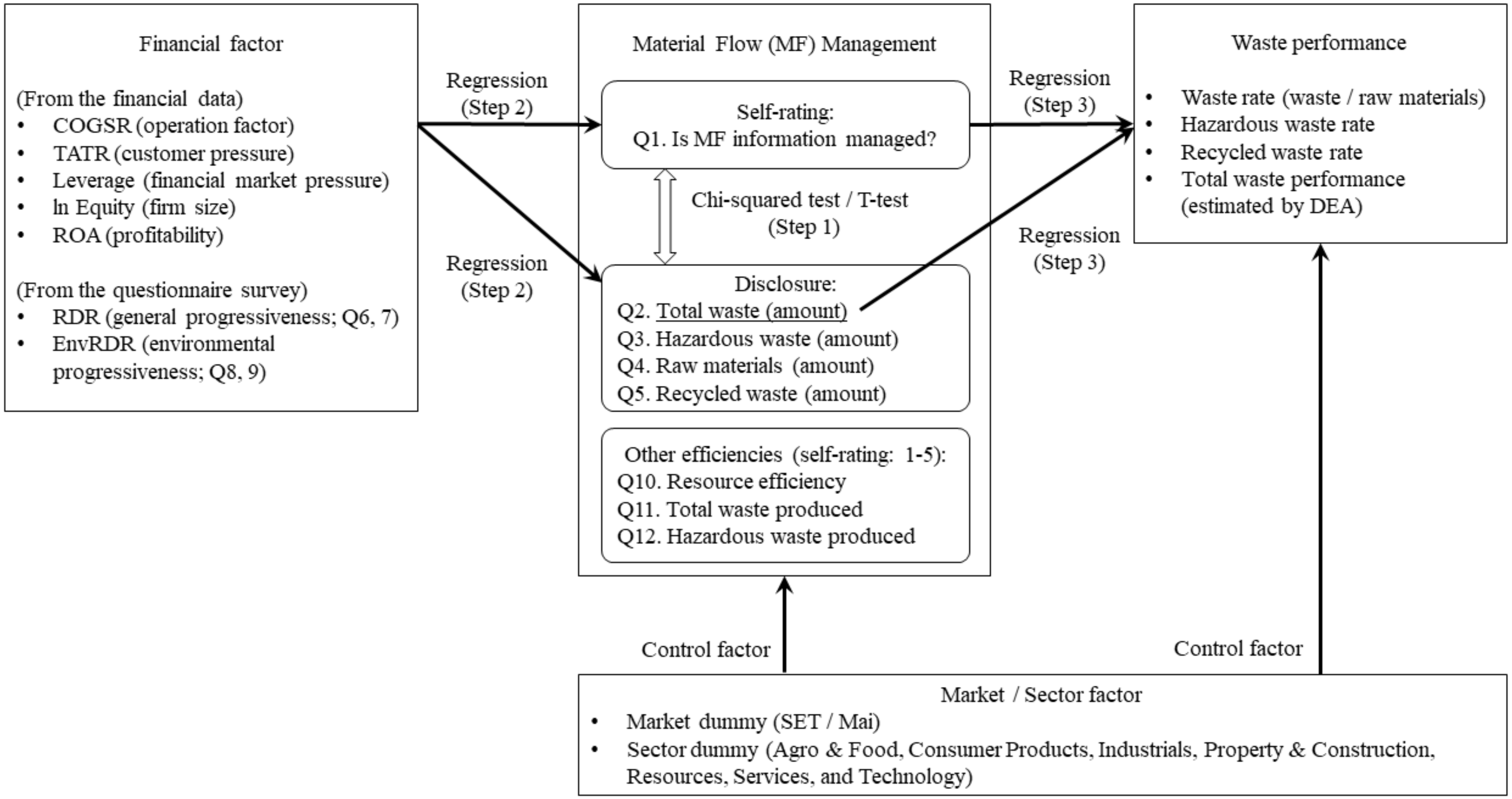

Figure 1. Research framework

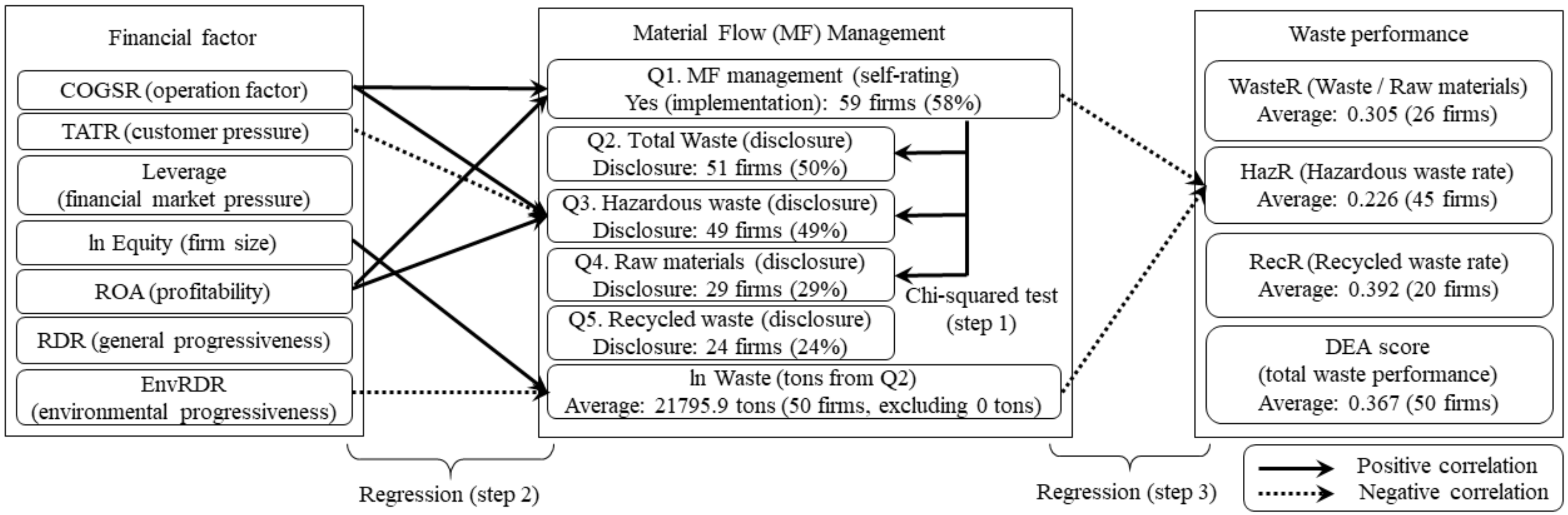

Figure 2. Results of this study

Table 1. Questionnaire items

#	Questionnaire items	Answer
	Material flow (MF) management (self-rating)	
Q1	Our company manages information on material flow (in the latest year).	1. Yes / 2. No
	MF Disclosure	
Q2	Total amount of waste produced, both hazardous and non-hazardous	1. Metric tons. / 2. No data
Q3	Total amount of hazardous waste produced	1. Metric tons. / 2. No data
Q4	Total amount of raw materials consumed	1. Metric tons. / 2. No data
Q5	Total amount of waste recycled	1. Metric tons. / 2. No data
	R&D activities	
Q6	Our firm has conducted Research and development (R&D) activities (in the latest year).	1. Yes / 2. No
Q7	If Yes above, please describe the total amount of R&D expense (in the latest year).	1. THB (Thai Baht) / 2. No data
Q8	Our firm has conducted R&D activities for environmental technology (in the latest year).	1. Yes / 2. No
Q9	If Yes above, please describe the proportion of R&D expenses for environmental technology to the total R&D expenses (in the latest year).	1. Percentage (%) / 2. No data
	[Other efficiencies] In comparison with average firms in your industry, how would you evaluate the performance of your firm over the last three years in terms of the following indicator:	
Q10	Resource efficiency	Likert scale: 1 to 5 (better)
Q11	Total amount of waste produced	Likert scale: 1 to 5 (better)
Q12	Total amount of hazardous waste produced	Likert scale: 1 to 5 (better)

Table 2. Target and respondent firms

	Total active firms	Target firms (Non-financial firms)	Respondent firms	Response rate
Firms in SET & Mai	663	596	101	16.9%
Markets				
Firms in SET	525	466	78	16.7%
Firms in Mai	138	130	23	17.7%
Industries				
Agro & Food	59	59	8	13.6%
Consumer Products	50	50	8	16.0%
Industrials	124	124	37	29.8%
Property & Construction	112	112	11	9.8%
Resources	60	60	17	28.3%
Services	143	143	15	10.5%
Technology	48	48	5	10.4%

Table 3. T-tests of five variables for sample selection bias

	Total obs	Censored firms (495)		Uncensored firms (101)		Difference of average	t-value	Probability
		Obs	Average (SD)	Obs	Average (SD)			
Revenue	584	485	485,731,500 (2,565,575,677)	99	215,483,165 (588,132,019)	270,248,335	1.042	0.298
COGS	576	477	387,161,460 (2,175,526,837)	99	174,515,387 (507,913,983)	212,646,073	0.967	0.334
EBIT	582	483	46,656,952 (256,425,605)	99	20,070,702 (43,060,126)	26,586,250	1.028	0.304
Total Assets	582	483	711,917,024 (3,341,087,918)	99	381,899,845 (1,036,849,359)	330,017,179	0.973	0.331
Total Equity	582	483	331,165,728 (1,702,221,467)	99	198,430,107 (465,893,989)	132,735,621	0.770	0.442

Notes: Currency unit is USD. SD stands for standard deviation.

Table 4. Results of questionnaire survey, from Q1 to Q9

#	Description	Yes	No	Values disclosed	n/a	No answer	Total
Q1	MF management (self-rating)	59	37	--	--	5	101
Q2	Total waste (disclosure)	--	--	51	45	5	101
Q3	Hazardous waste (disclosure)	--	--	49	42	10	101
Q4	Raw materials consumed (disclosure)	--	--	29	64	8	101
Q5	Recycled waste (disclosure)	--	--	24	65	12	101
Q6	R&D activities (self-rating)	41	59	--	--	1	101
Q7	R&D expense (disclosure)	--	--	25	3	73	101
Q8	Environmental R&D activities (self-rating)	23	71	--	--	7	101
Q9	Environmental R&D proportion (disclosure)	--	--	13	2	86	101
	Disclosure values	Responses	Average	SD	Median	Min	Max
Q2	Total waste (tons)	51	21368.5	141505.6	190	0	1011895
Q3	Hazardous waste (tons)	49	4113.9	27246.2	20	0	190847
Q4	Raw materials consumed (tons)	29	904754.7	4258886.8	9147.95	0	22998801
Q5	Recycled waste (tons)	24	27036.2	126267.5	31.925	0	619718
Q7	R&D expense (THB)	25	4120232	7422089	2000000	45455	31710000
Q9	Environmental R&D proportion (%)	13	19.2	26.7	5	0.01	90

Notes: The value of total waste (Q2) includes 1 observation stating 0 tons. Average value of total waste excluding this response is 21795.9 tons (50 firms).

Table 5. Results of questionnaire survey, from Q10 to Q12

#		Answer						Average score	(SD)
		5 (better)	4	3	2	1	No answer		
Q10	Resource efficiency	16	34	42	3	2	4	3.608	(0.873)
Q11	Efficiency of waste produced	13	41	37	5	3	2	3.566	(0.894)
Q12	Efficiency of hazardous waste produced	14	40	37	3	4	3	3.582	(0.919)

Table 6. Chi-squared test of Q1 and other answers (total 101 firms) (step 1)

#	Description	Answer	Q1. MF management (self-rating) Yes	No (or no answer)	Chi-squared	Probability
Q2	Total waste	Values are disclosed	37	14	8.471***	0.004
		n/a (or no answer)	22	28		
Q3	Hazardous waste	Values are disclosed	36	13	8.878***	0.003
		n/a (or no answer)	23	29		
Q4	Raw materials consumed	Values are disclosed	21	8	3.281*	0.070
		n/a (or no answer)	38	34		
Q5	Recycled waste	Values are disclosed	16	8	0.882	0.348
		n/a (or no answer)	43	34		
Q6	R&D activities (self-rating)	Yes	29	12	4.310**	0.038
		No (or no answer)	30	30		
Q7	R&D expense	Values are disclosed	16	9	0.567	0.451
		n/a (or no answer)	43	33		
Q8	Environmental R&D activities (self-rating)	Yes	15	8	0.567	0.451
		No (or no answer)	44	34		
Q9	Environmental R&D proportion	Values are disclosed	6	7	0.924	0.337
		n/a (or no answer)	53	35		

Notes: ***, **, and * denote statistically significant levels of 1%, 5%, and 10%, respectively. Chi-squared tests are based on a degree of freedom of 1.

Table 7. T-test of Q1 and self-rating performance (Q10 to Q12) (step 1)

#	Description	Q1 MF management: Yes		Q1 MF management: No (or no answer)		t-value	Probability
		Obs	Average (SD)	Obs	Average (SD)		
Q10	Resource efficiency	56	3.679 (0.811)	39	3.538 (0.942)	−0.775	0.440
Q11	Total waste produced	57	3.649 (0.744)	40	3.475 (1.062)	−0.950	0.344
Q12	Hazardous waste produced	56	3.679 (0.765)	40	3.475 (1.086)	−1.078	0.284

Table 8. Descriptive statistics

Variable	Obs	Average	SD	Min	Max
Dummy for Q1 to Q5					
DumQ1	99	0.586	0.495	0	1
DumQ2	99	0.515	0.502	0	1
DumQ3	99	0.495	0.503	0	1
DumQ4	99	0.293	0.457	0	1
DumQ5	99	0.242	0.431	0	1
Financial variables					
COGSR	99	0.746	0.175	0.003	1.068
TATR	99	0.890	0.610	0.088	3.535
Leverage	99	2.032	1.477	1.038	9.786
lnEquity	99	17.906	1.452	14.492	21.730
ROA	99	0.072	0.083	−0.246	0.380
RDR	99	0.070	0.285	0	2.420
EnvRDR	99	2.525	11.390	0	90
Dummy variables					
DumMai	99	0.232	0.424	0	1
DumAgro	99	0.081	0.274	0	1
DumCons	99	0.081	0.274	0	1
DumInd	99	0.374	0.486	0	1
DumProp	99	0.111	0.316	0	1
DumRes	99	0.162	0.370	0	1
DumServ	99	0.141	0.350	0	1
Waste amounts					
lnWaste	50	5.598	2.724	−3.507	13.827
Waste performance					
WasteR	26	0.305	0.533	7.45E−06	2.200
HazR	45	0.226	0.268	0	1
RecR	20	0.392	0.402	0	1
DEA score	50	0.367	0.343	0	0.983

Note: lnWaste excludes 1 observation stating 0 tons.

Table 9. Results of the logistic and OLS regression models (step 2)

	1	2	3	4	5	6	7
Dep. var.	DumQ1	DumQ2	DumQ3	DumQ4	DumQ5	lnWaste	lnWaste
Method	Logit	Logit	Logit	Logit	Logit	OLS	OLS
	Coef (SE)	Coef (SE)	Coef (SE)	Coef (SE)	Coef (SE)	Coef (SE)	Coef (SE)
COGSR	4.240*	1.407	5.455**	−1.400	−2.806	−0.703	−1.370
	(2.177)	(1.921)	(2.703)	(1.859)	(1.842)	(2.342)	(2.461)
TATR	−0.203	−0.366	−1.679**	−0.296	0.508	0.550	0.952
	(0.497)	(0.500)	(0.795)	(0.507)	(0.482)	(0.914)	(0.891)
Leverage	0.291	−0.197	−0.154	0.144	−0.682	0.317	0.419
	(0.259)	(0.191)	(0.196)	(0.187)	(0.515)	(0.281)	(0.275)
lnEquity	0.260	−0.011	−0.074	−0.083	0.396	0.971***	1.059***
	(0.257)	(0.230)	(0.246)	(0.241)	(0.291)	(0.312)	(0.378)
ROA	8.135*	1.532	12.071**	5.053	3.665	0.195	−3.241
	(4.390)	(3.904)	(5.300)	(3.829)	(4.592)	(4.820)	(5.139)
RDR	−0.021	−0.784	0.401	−2.783	−0.158	0.602	0.310
	(1.239)	(1.090)	(0.907)	(2.516)	(0.988)	(2.388)	(2.187)
EnvRDR	−0.017	−0.038	−0.061	−0.018	−0.034	−0.142	−0.214*
	(0.022)	(0.035)	(0.050)	(0.023)	(0.043)	(0.099)	(0.106)
DumMai	0.918	−0.480	−0.336	0.697	1.076		0.280
	(0.776)	(0.703)	(0.750)	(0.742)	(0.815)		(1.242)
DumAgro	1.978	−0.607	−0.282	15.064	−1.325		5.493**
	(1.448)	(1.259)	(1.244)	(1480.092)	(1.682)		(2.373)
DumCons	1.855	1.493	2.663*	16.418	−1.135		2.394
	(1.305)	(1.285)	(1.537)	(1480.092)	(1.742)		(1.948)
DumInd	1.301	1.534	1.183	15.613	0.967		2.156
	(1.070)	(1.040)	(1.074)	(1480.092)	(1.274)		(1.746)
DumProp	−0.722	0.699	0.399	15.369	0.694		4.236*
	(1.275)	(1.148)	(1.196)	(1480.092)	(1.404)		(2.196)
DumRes	0.217	0.008	0.035	15.625	0.356		0.998
	(1.130)	(1.089)	(1.152)	(1480.092)	(1.340)		(2.029)
DumServ	0.859	0.145	−0.933	14.093	−0.314		−0.678
	(1.156)	(1.118)	(1.222)	(1480.092)	(1.474)		(2.027)
Constant	−9.447*	−0.672	−2.332	−14.143	−6.320	−12.301*	−15.585*

	(5.368)	(4.656)	(4.953)	(1480.100)	(5.710)	(6.456)	(7.819)
Number of obs	99	99	99	99	99	50	50
LR chi^2	26.93**	20.44	30.46***	15.21	18.34		
Pseudo R^2	0.201	0.149	0.222	0.127	0.167		
Log likelihood	−53.688	−58.357	−53.385	−52.265	−45.664		
F value						2.39**	2.75***
R^2						0.285	0.524
Adj R^2						0.166	0.333

Notes: This table shows the estimated results of logistic and OLS regression models. Values with and without parentheses are coefficients and standard error, respectively. ***, **, and * denote statistically significant levels of 1%, 5%, and 10%, respectively. LR chi^2 is the statistics for the likelihood ratio chi-squared test checking if there is no effect from all independent variables. F value is the F statistic testing if there is no effect from all independent variables.

Table 10. Waste performance by each market and each industry

	WasteR		HazR		RecR		DEA score	
	obs	Avg (SD)	obs	Avg (SD)	obs	Avg (SD)	obs	Avg (SD)
Total	26	0.305 (0.533)	45	0.226 (0.268)	20	0.392 (0.402)	50	0.367 (0.343)
Markets								
SET	20	0.314 (0.578)	39	0.227 (0.258)	16	0.480 (0.404)	42	0.342 (0.331)
Mai	6	0.276 (0.386)	6	0.222 (0.355)	4	0.042 (0.050)	8	0.496 (0.397)
Industries								
Agro & Food	2	0.283 (0.024)	1	0.003 (--)	1	0.954 (--)	2	0.382 (0.540)
Consumer products	4	0.834 (1.023)	5	0.204 (0.205)	1	0.050 (--)	5	0.396 (0.369)
Industrials	12	0.248 (0.462)	25	0.226 (0.280)	12	0.356 (0.421)	26	0.443 (0.353)
Property & Construction	2	0.163 (0.228)	3	0.418 (0.508)	1	0.032 (--)	4	0.203 (0.238)
Resources	4	0.079 (0.158)	6	0.183 (0.214)	3	0.489 (0.444)	6	0.160 (0.212)
Services	2	0.208 (0.271)	3	0.190 (0.178)	2	0.475 (0.530)	5	0.430 (0.418)
Technology	0	-- (--)	2	0.286 (0.343)	1	0.472 (--)	2	0.080 (0.113)

Table 11. Regression results (step 3)

	1	2	3	4	5	6	7	8
Dep. var.	WasteR	WasteR	HazR	HazR	RecR	RecR	DEA score	DEA score
	Coef (SE)	Coef (SE)	Coef (SE)	Coef (SE)	Coef (SE)	Coef (SE)	Coef (SE)	Coef (SE)
DumQ1 (MF management)	−0.247	−0.262	−0.241***	−0.221**	0.043	0.044	0.031	−0.008
	(0.246)	(0.258)	(0.081)	(0.093)	(0.209)	(0.219)	(0.113)	(0.122)
lnWaste	0.032	0.036	−0.039**	−0.040**	0.021	−0.033	0.005	0.016
	(0.048)	(0.061)	(0.015)	(0.017)	(0.045)	(0.063)	(0.018)	(0.021)
DumMai		0.068		−0.004		−0.527*		0.081
		(0.305)		(0.119)		(0.255)		(0.145)
DumAgro		--		−0.101		0.644		0.229
		--		(0.318)		(0.660)		(0.364)
DumCons		0.610		−0.074		−0.428		0.293
		(0.527)		(0.213)		(0.582)		(0.297)
DumInd		0.025		−0.082		0.091		0.328
		(0.505)		(0.190)		(0.455)		(0.263)
DumProp		−0.046		0.076		−0.370		0.081
		(0.661)		(0.242)		(0.597)		(0.322)
DumRes		−0.179		−0.100		0.161		0.047
		(0.508)		(0.211)		(0.547)		(0.293)
DumServ		−0.034		−0.099		0.265		0.366
		(0.666)		(0.230)		(0.527)		(0.299)
Constant	0.308	0.210	0.633***	0.696***	0.236	0.567	0.318**	0.010
	(0.299)	(0.713)	(0.111)	(0.215)	(0.295)	(0.516)	(0.143)	(0.294)
Number of obs	26	26	45	45	20	20	50	50
F value	0.61	0.74	7.73***	1.63	0.16	0.91	0.07	0.73
R^2	0.050	0.257	0.269	0.295	0.018	0.449	0.003	0.141
Adj R^2	−0.032	−0.093	0.234	0.114	−0.098	−0.046	−0.040	−0.053

Notes: This table shows the estimated results of a regression model (OLS). Values with and without parentheses are coefficients and standard error, respectively. ***, **, and * denote statistically significant levels of 1%, 5%, and 10%, respectively. F value is the F statistic testing if there is no effect from all independent variables.

Supplementary material. DEA model

The DEA model has had a long history since Charnes et al. (1978) (Emrouznejad and Yang, 2018). In particular, it is used in many articles in the field of environment and energy (Tyteca, 1996; Zhou et al., 2008). In this field, most studies employ Shephard technology, assuming variable returns to scale, and also often treat undesirable output such as carbon dioxide by assuming weak disposability. In the field of operations research in recent years, it has been argued that the classic weakly disposable Shephard technology is non-convex; for weak disposability, methods other than Shephard technology are being proposed (Kuosmanen and Kazemi Matin, 2011; Leleu, 2013). Therefore, this study adopts the Kuosmanen weakly disposable technology used by Kuosmanen and Kazemi Matin (2011).

The model in this study uses sales as a desirable output, total waste as an undesirable output, and COGS and total assets as its two inputs. The model aims to maximize sales and minimize total waste, given these two inputs. It adopts the Kuosmanen weakly disposable technology used by Kuosmanen and Matin (2011). Following Kuosmanen and Kazemi Matin (2011) and Leleu (2013), this study defines a production set as $P_O^t(x^t)$, where input vector x can produce output vector (v, w) in time t (year t). Subscript "o" means output function. v and w denote desirable and undesirable outputs, respectively. Specifically, suppose there is a m-th x, n-th v, and j-th w. Here, all observed DMUs are assumed to be technically feasible. Suppose x and v are freely disposable and $P_O^t(x^t)$ is convex. Weak disposability is assumed as follows:

$$\begin{aligned} &\text{If} \left(v^t, w^t\right) \in P_o^t\left(x^t\right) \text{ and } 0 \le \theta \le 1 \text{ then } \left(\theta v^t, \theta w^t\right) \in P_o^t\left(x^t\right) \\ &\text{If} \left(v^t, w^t\right) \in P_o^t\left(x^t\right) \text{ and } w^t = 0, v^t = 0 \end{aligned} . \tag{A.1}$$

Kuosmanen weakly disposable technology allows "abatement factors θ to differ across firm" (Kuosmanen and Kazemi Matin, 2011). This is different from the classic Shephard technology in that the simple abatement factor θ is the same across DMUs.

In general, a directional distance function (DDF) $\overrightarrow{D_{Ko}^t}(x^t, v^t, w^t)$ is defined as follows:

$$\overrightarrow{D_{Ko}^t}\left(x^t, v^t, w^t; g^v, g^w\right) = \sup\left\{\delta : \left(v^t + \delta g^v, w^t - \delta g^w\right) \in P_o^t\left(x^t\right)\right\} \tag{A.2}$$

where g denotes the directional vector $g = (g^v, g^w)$. This study sets $g^t = (g^{t,v}, g^{t,w}) = (v^t, w^t)$

as a proportional weight. This setting means that in the frontier direction, a 1% increase in *v* and a 1% decrease in *w* are equivalent. Suppose there are *k* peer DMUs from 1 to *K*, and *k'* is a certain evaluated DMU. $\overrightarrow{D_{Ko}^{t}}(x^t, v^t, w^t; g^v, g^w)$ (the value of DDF relative to the Kuosmanen output technology) is represented as the following primal problem:

$$
\begin{aligned}
&\max_{\delta,\lambda,\mu} \delta \\
&s.t. \quad \sum_{k=1}^{K} \lambda_k v_{m,k} \geq v_m^{k'} + \delta g_m^v \qquad m = 1,\ldots,M \\
&\qquad \sum_{k=1}^{K} \lambda_k w_{j,k} = w_j^{k'} - \delta g_j^w \qquad j = 1,\ldots,J \\
&\qquad \sum_{k=1}^{K} (\lambda_k + \mu_k) x_{n,k} \leq x_n^{k'} \qquad n = 1,\ldots,N \\
&\qquad \sum_{k=1}^{K} (\lambda_k + \mu_k) = 1 \\
&\qquad \lambda_k \geq 0 \qquad k = 1,\ldots,K \\
&\qquad \mu_k \geq 0 \qquad k = 1,\ldots,K
\end{aligned}
\quad . \tag{A.3}
$$

λ denotes "intensity weights of inputs actively used in production" whereas μ denotes "weights of inputs that are held idle" (Kuosmanen and Kazemi Matin, 2011). In the problem, variable returns to scale are assumed by setting the sum of λ and μ to be unity.

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