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Abstract

In the Sustainable Development Goals (SDGs) adopted by the United Nations (UN), goal 12 ("ensure sustainable consumption and production [SCP] patterns") has eight outcome targets (12.1–12.8) and three targets for the means of implementation (MoI) (12.a–12.c). This "SCP-via-SDGs" approach is a much narrower, specific concept based on historical agreements that range from the Stockholm conference (1972) to the 10-Year Framework of Programmes (10YFP) (2012–2022). Meanwhile, "the academic SCP" is a highly interdisciplinary and complex approach that pursues an answer to what sustainability is, and it has not explicitly provided the SCP-via-SDGs framework at present. Thus, this study proposes a five-by-five framework for the SCP-via-SDGs approach from the production perspective (i.e., for individual firms), following the literature on corporate environmental management. The five stages (I–V) consider environmental management systems (EMS; I. strategy and process) for target 12.4, environmental management accounting (EMA; II. accounting and disclosure) for 12.6, and environmental management control systems (EMCS; III. financial, IV. environmental, and V. overall performance) for 12.2. Meanwhile, the five factors (1–5) consider the baseline and material flow (MF) factors (total waste, hazardous waste, raw materials used, and recycled waste) for targets 12.3 and 12.5. As an application, this study surveyed non-financial listed firms in Vietnam and compared the results to a previous study on Thailand. The results show that the firms are more likely to be at stage III (financial performance of EMCS) in Thailand and stage I or II (EMS or EMA) in Vietnam, suggesting that each market requires its own SCP policies, depending on

the economic growth of each.

Keywords: Sustainable development goals; Sustainable consumption and production; Environmental management systems; Environmental management accounting; Thailand and Vietnam
JEL codes: M11, Q53, Q56

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Highlights

- Five-by-five framework for SCP-via-SDGs from the production perspective was proposed
- The five stages included EMS and EMA for specific instruments and EMCS for efficiency
- The five factors were the baseline and four MF factors of waste and raw materials
- The survey of non-financial listed firms in Thailand and Vietnam was conducted
- Presumably, Thailand was at stage III (EMCS), and Vietnam was at stage I&II (EMS&EMA)

1. Introduction

The Sustainable Development Goals (SDGs), adopted by the United Nations (UN) in September 2015 (UN, 2015), consist of 17 different goals, with goal 12 being to "ensure sustainable consumption and production (SCP) patterns" (the short name is "responsible consumption and production"). This goal has eight outcome targets (12.1–12.8) and three targets for the means of implementation (MoI) (12.a–12.c) (Figure 1; for detail, see Appendix Table A1) with corresponding indicators (Supplementary Information Table S1). Regarding the short history of SCP in Figure 1 (UN Environment Programme [UNEP], 2015; for the key part of original text, see Supplementary Information Tables S2–S7; for another view, see Bengtsson et al., 2018), before the 10-Year Framework of Programmes (10YFP) (1972–2012), the Stockholm conference (UN Conference on the Human Environment; UN, 1972), and "the limits to growth" (Meadows et al., 1972) argued for decoupling economic growth from environmental degradation. The Rio declaration on Environment and Development (UN Conference on Environment and Development, 1992) outlined key principles for SCP (mainly the 7th, 11th, 15th, and 16th principles) in Agenda 21 as part of its action plan. In the Johannesburg Plan of Implementation from the World Summit on Sustainable Development, chapter III called for action to "encourage and promote the development of a 10YFP" on SCP (UN, 2002, paragraphs 14–25). SCP was then further defined in the Oslo Symposium held by the UN Commission on Sustainable Development in 1994 as "the use of goods and services that respond to basic needs and bring a better quality of life, while minimising the use of natural resources, toxic materials, and emissions of waste and pollutants over the life cycle, so as not to jeopardise the needs of future generations" (Norwegian Ministry of Environment, 1995; UNEP, 2015). As a response to the Rio declaration, the Marrakesh Process (2003–2011) conducted seven Marrakech Task Forces for the 10YFP (UNEP, 2011). Afterward, the UN Conference on Sustainable Development (Rio+20) reaffirmed the importance of SCP and adopted the 10YFP in 2012 (UN, 2012, paragraphs 224–226).

However, there is a considerable gap between the SCP within SDGs (hereafter "SCP-via-SDGs") approach and SCP in the academic literature ("the academic SCP"). While the former is a much narrower and more specific concept with only the eight outcomes and three MoI targets (Figure

1), the latter is a highly interdisciplinary and complex concept that pursues an answer to what sustainability is (e.g., Lukman et al., 2016; Vergragt et al., 2014; 2016; for the literature review, see Supplementary Information Tables S8–S9). Specifically, the academic SCP proposes two approaches to reduce the environmental burden, namely, the efficiency (within business as usual [BAU]) and systemic (beyond BAU) approaches. The SCP-via-SDGs approach focuses only on the efficiency approach because firms in the private sector cannot usually go beyond BAU. Meanwhile, the SCP-via-SDGs approach overlooks the systemic approach (Bengtsson et al., 2018) because it often requires a restructuring of the whole society and supply chain in terms of SCP (e.g., through sharing business, communication, and education).

Thus, as its research motivation, this study presupposes that the production side requires a realistic framework of the SCP-via-SDGs approach rather than the academic SCP because the academic SCP is often too complicated and lacks for coherent approaches. Usually, firms are not superheroes for SDGs and cannot become big development actors ("big D") (Scheyvens et al., 2016). Meanwhile, SDGs are a gift to business, providing a guide to future markets over the coming decades (Pedersen, 2018). Therefore, certain firms would like to contribute to the SDGs to some extent while seeking potential profitability in the long term.

This study proposes a five-by-five matrix framework for the SCP-via-SDGs approach from the production perspective (as the bottom-up approach). The framework corresponds to the five outcome targets on the production side: 12.2 (natural resources), 12.3 (food losses), and 12.5 (waste) for environmental efficiency (on both the consumption and production sides); 12.4 (chemical management on the production side); and 12.6 (sustainable practice/information). The five stages (I–V) follow the literature on corporate environmental management (Guenther et al., 2016), including environmental management systems (EMS; I. strategy and process) for target 12.4, environmental management accounting (EMA; II. accounting and disclosure) for 12.6 as specific environmental instruments, and environmental management control systems (EMCS; III. financial, IV. environmental, and V. overall performance) for 12.2 as the efficiency approach. Meanwhile, the five factors (1–5) consider the baseline and material flow (MF) factors (total waste, hazardous waste, raw materials used,

and recycled waste) for targets 12.3 and 12.5, following previous results in Thailand (Yagi and Kokubu, 2018), which found that Thai companies manage in this order.

As an application, this study surveys non-financial listed firms in Vietnam, comparing the results to a previous study on Thailand (Yagi and Kokubu, 2018). This research aims to confirm the differences in the degree of MF management depending on economic development (although, as a limitation, two cases are too small to extrapolate to all countries in the world). Thailand and Vietnam are, at first glance, similar because they are developing ASEAN countries but, in fact, they have divergent amounts of gross domestic product per capita (6,595 U.S. dollars [USD] in Thailand and 2,342 USD in Vietnam as of 2017, as per the World Bank database). This difference is slightly narrower than that between China (8,827 USD) and India (1,942 USD).

The structure of this study is as follows. Section 2 explains the background of SCP and corporate environmental practices (EMS, EMA, and EMCS). Section 3 proposes an SCP-via-SDGs framework from the production perspective and applies it to firms in Thailand and Vietnam. Section 4 shows the application results and provides a discussion, and Section 5 concludes.

2. Literature Review

2.1 The Academic SCP

Regarding the academic SCP, when using the keyword "SCP" in the Web of Science (Core Collection) provided by Clarivate Analytics (Philadelphia, U.S.), 191 (topic search) and 54 (title search) peer-reviewed articles were found from 1990 to 2019 (Supplementary Information Tables S8–S9). Among these, the *Journal of Cleaner Production* (JCLP) has published the most articles (54 for topic and 19 for search) and, hence, is the leading journal on SCP. This subsection introduces 34 peer-reviewed articles briefly, of which 33 articles have "SCP" in the title, while Vergragt et al. (2014) includes "sustainable production, consumption" in its title (among these, 20 articles were published in JCLP). Note that, among the main fields, this study chooses the environmental sciences field to review about corporate management, not a specific technology. Because the SCP studies are highly interdisciplinary, this study roughly uses the following three perspectives: the governmental (or

general) perspective (e.g., policy and research), the consumption perspective (e.g., demand and use), and the production perspective (e.g., supply).

From the governmental perspective, SCP policies have been most likely to be the most advanced in UNEP and the EU (in particular, Finland). The case studies of the SCP policies were UNEP activities, including 10YFP (Clark, 2007), the Joint Research Centre site in Italy (De Camillis et al., 2012) and the Communication on the SCP (Nash, 2009) by the European Commission, the Sustainable Consumption Research Exchange network (SCORE!; Tukker et al., 2008), and product labelling schemes in the EU (Dendler, 2014). Moreover, the specific countries examined were 25 in the EU (Liobikienė and Dagiliūtė, 2016), Finland (Berg and Hukkinen, 2011a, 2011b; Honkasalo, 2011), the post-Soviet republics (nine countries from 1990–2010; Brizga et al., 2014), Lithuania (Jonkutė and Staniškis, 2019), Asian countries (Tseng et al., 2013; Zhao and Schroeder, 2010), and China (Schroeder, 2014).

Some research schemes have been developed for SCP. Lukman et al. (2016) proposed the sustainability terminology system (pyramid), which includes 46 terms in four sub-layers. Vergragt et al. (2014) introduced four research frameworks, 11 enabling mechanisms, and nine main research areas, whereas Vergragt et al. (2016) introduced ten different themes for SCP from 40 selected papers. Sakao (2019) proposed a model to review such SCP studies for transdisciplinary assessment. In addition, the literature has suggested that SCP policies have several aspects. Specifically, the SCP policies have three layers related to everyday life, the market economy, and global capitalism (Brodhag, 2010); three typical positions that are reformist, revolutionary, and involve reconfiguration (Geels et al., 2015); and two possible options of a stand-alone goal and a cross-cutting objective that is embedded in other goals (Akenji and Bengtsson, 2014). Such SCP policies aim at correcting for either market failures or systems failures (Stevens, 2010). As a specific method, De Camillis and Goralczyk (2013) proposed new market-based instruments based on a value added tax and life cycle thinking.

From the consumption perspective, SCP studies have focused mainly on “smart consumption.” Ülkü and Hsuan (2017) proposed modeling a green consumer’s decision-making for two competing products. Researches on the sharing economy include sharing cities-SCP typology for

cities (Cohen and Muñoz, 2016), sharing mobility businesses in China (Ma et al., 2019), and three case studies in the U.S., Japan, and India (Schroeder et al., 2019).

Finally, from the production perspective, SCP studies have focused mainly on how to raise environmental awareness among stakeholders and how to improve the environmental efficiency of the supply chain. Regarding the former, Dobes (2016) applied a new diagnostic tool to study 57 companies in the Czech Republic, while Dubey et al. (2016) examined the top management beliefs and participation of 167 Indian organizations. The latter literature examined 738 manufacturers of auto components in India (Dubey et al., 2018), a Finnish pulp and paper mill (Lehtoranta et al., 2011), and case studies that involved the production of canned tuna in sunflower oil and a frozen chicken snack in Thailand (Mungkung et al., 2012). In addition, the model for SCP evaluation in the supply chain was developed (Luthra et al., 2017; Mangla et al., 2017).

2.2 The Differences between the SCP-via-SDGs Approach and the Academic SCP

The SCP-via-SDGs approach consists of eight outcome targets (12.1–12.8) and three MoI targets (12.a–12.c) (Figure 1). Those targets mainly related to production would be 12.2 (resource efficiency), 12.3 (food losses), 12.4 (chemicals/wastes), 12.5 (waste reduction), and 12.6 (sustainable practices/information). As reasons for such a classification, targets 12.2, 12.3, and 12.5 are related to environmental efficiency, both on the consumption and production sides. Target 12.4 is usually on the production side because it requires chemical management. Target 12.6 is clearly on the production side because it requires companies to improve their levels of sustainability and transparency.

Compared to the academic SCP, the SCP-via-SDGs approach is a much narrower concept. Following Bengtsson et al. (2018), the academic SCP has suggested approaches that are both efficient (within BAU) and systemic (beyond BAU). That is, the amount of resource use (*Resource*) is equal to resource use per activity (*Activity*) times the volume of activities:

$$Resource = \frac{Resource}{Activity} \times Activity \quad (1)$$

The efficiency approach aims to reduce *Resource*-per-*Activity*, by promoting more efficient production methods and products, etc. Meanwhile, the systemic approach seeks to minimize *Activity* by changing

the production system itself (e.g., tackling the overall volumes of consumption, tackling distributional issues, and making related social and institutional reforms). Bengtsson et al. (2018) argued that the SCP-via-SDGs approach overlooks the systemic approach as follows. Target 12.1 is just a reconfirmation of the 10YFP, while target 12.2 (resource efficiency) is difficult to operationalize. Targets 12.3 (food losses), 12.4 (chemicals/wastes), and 12.5 (waste reduction) fail to challenge the existing production system to reduce its volume of consumption. There is also no evidence about whether targets 12.6 (sustainable reporting), 12.7 (sustainable public procurement), or 12.8 (lifestyles and education) would decrease the environmental burden even if any or all of them were achieved.

Also, in a manner different from the SCP-via-SDGs approach, the academic SCP often (1) takes the top-down perspective, and it relies highly on (2) consumption side and (3) supply chain management. Regarding (1), generally, the academic SCP takes the top-down (e.g., policy makers) perspective to go beyond BAU. As an advantage, it can change the whole society if it were properly implemented. It provides a disadvantage, however, because it is often too complicated, causing firms and other development actors to be more likely to lack coherent approaches (Scheyvens et al., 2016).

Regarding (2), usually academic SCP relies heavily on "smart consumption." This sounds good, but it is usually difficult to implement for consumers and firms at several points. First, they cannot afford to develop environmentally-friendly products/services because their budgets are finite. Second, eco-labeling is important for SCP, but it should be implemented by a third party or the relevant government entity, not individual firms, in order to avoid confusion in the market. Finally, a sharing business may be necessary for SCP, but firms do not necessarily invest in this because it is often difficult to forecast which of the businesses will succeed.

Finally, regarding (3), the academic SCP also relies on supply chain management from the production perspective, which is ideal for managing the whole industry. Indeed, if there is a capital relationship in the supply chain, a consistent SCP policy could be introduced within group firms. Otherwise, however, individual firms may not necessarily be able to afford to manage the whole supply chain to seek SCP. Scheyvens et al. (2016) argued that firms need to go beyond BAU to be "big D" actors in terms of SDGs, but that doing so is impractical given the existing business situation.

2.3 The Three systems of Corporate Environmental Management for SCP: EMS, EMA, and EMCS

As noted in the above discussion, it is often difficult and too complicated for firms to undertake SCP/SDGs. However, many firms seem to want to do it because the SDGs approach would be beneficial to their business (Pedersen, 2018). That is, although there is still a great distance between high-level political agreements and the real market, the SDGs approach can make firms look to the future and can offer them market guidance as to new business opportunities and development.

When implementing SCP, however, firms are not often willing to consult the academic SCP literature (Section 2.1) because it is often too complicated and exceeds BAU. Instead, this study supposes that firms can follow approaches from the literature on corporate environmental management because they are systematized for firms. The three primary tools for SCP are EMS, EMA (including material flow cost accounting [MFCA]), and EMCS (Guenther et al., 2016). Of the first two, EMS can be defined as "part of the management system used to manage environmental aspects, fulfil compliance obligations, and address risks and opportunities," in which the management system is a "set of interrelated or interacting elements of an organization to establish policies and objectives and processes to achieve those objectives" (ISO14001:2015, 2015). Meanwhile, EMA can be broadly defined as "the identification, collection, estimation, analysis, internal reporting, and use of physical flow information (i.e., materials, water, and energy flows), environmental cost information, and other monetary information for both conventional and environmental decision-making within an organization" (UN Division for Sustainable Development, 2001).

The third tool, EMCS, is a relatively new concept for considering environmental capacity. Management control systems (MCS) are popular in the field of business administration and can be defined as "the formal, information-based routines and procedures managers use to maintain or alter patterns in organizational activities" (Simons, 1994, 1995). EMCS is environmental MCS and is comprised of systems that are between the strategic and operational levels (Guenther et al., 2016) while being a concept that goes beyond EMS and EMA. Compared to EMS, EMCS consists of "various controls such (as) cybernetic, cultural, or administrative controls" (Guenther et al., 2016).

Moreover, compared to EMA, EMCS aligns better with corporate behaviors, "routines, and strategies with the environmental strategies and objectives of the firm" (Guenther et al., 2016). Henri and Journeault (2010) argued that EMCS ("eco-control," to use their term) may foster environmental performance by providing feedback, information (for decision-making), organizational attention, and data (for external reporting).

Note that, as an EMA, MFCA has recently been standardized by ISO14051 (2011; general framework) and ISO14052 (2017; specifically for a supply chain). MFCA is a "tool for quantifying the flows and stocks of materials in processes or production lines in both physical and monetary units" (ISO14051, 2011, p. 3). MFCA gives companies an opportunity for increasing their levels of resource efficiency and cost reduction by improving the transparency of MF and costs. As per the MFCA studies in JCLP (the leading journal; Yagi and Kokubu, 2018, 2019), Rieckhof et al. (2015) proposed a five-stage model to examine how MFCA is integrated into MCS (EMCS) within a firm based on Simons (1994, 1995). Following Rieckhof et al. (2015), Yagi and Kokubu (2018) examined the MF management (as a previous step before MFCA) of non-financial listed firms in Thailand. Of the 101 respondent firms (the response rate was 16.9%), 58% answered that they were implementing MF management (self-rating). It was found that Thai companies manage (on average) general waste (the disclosure rate was 50%), hazardous waste (49%), raw material (29%), and recycling (24%), in that order.

3. Methods

3.1 The SCP Framework from the Production Perspective

This study proposes a realistic framework for the SCP-via-SDGs approach from the production perspective (i.e., for firms) by following the literature on corporate environmental management because the academic SCP has not explicitly provided this at the present time. This study supposes that the five focal targets (12.2 to 12.6) can be achieved by approaches used in corporate environmental management as follows. EMS is useful for target 12.4 (chemicals/wastes). EMA is crucial for target 12.6 (sustainable practice/information). EMCS will help improve environmental

efficiency for target 12.2 (the efficient use of natural resources). MFCA (as an EMA) is crucial for not only target 12.6 by improving the level of transparency but also target 12.2 by increasing resource efficiency. These EMS, EMA (MFCA), and EMCS with MF management would contribute to overall waste reduction for targets 12.5 (waste) and 12.3 (food losses).

In making this model, the following three things are considered further. First, because firms cannot usually go beyond BAU (Bengtsson et al., 2018), a realistic model should stay within BAU. Second, because firms cannot necessarily afford to manage the entire supply chain or their society, the model should consider an individual firm (as the bottom-up approach), not the whole supply chain. Finally, this study follows the findings by Yagi and Kokubu (2018) that Thai firms are likely to manage total waste, hazardous waste, raw materials, and recycled waste, in that order.

The model from this study is a five-by-five matrix with five stages of corporate environmental practices and five MF factors (Figure 2). “Stage” in the framework refers to an environmental managerial practice (or corporate sub-system). Stage I relates to development of the strategy and process (EMS) because EMS consists of “the formulation of specific environmental goals and the implementation of environmental processes and structures” (Guenther et al., 2016). Stage II relates to accounting and disclosure (EMA) because EMA “refers to tools, techniques, and instruments...intended to support managerial decision-making” (Guenther et al., 2016). EMS and EMA are analogous to specific environmental instruments such as end-of-pipe technology. This study supposes that firms tend to prioritize EMS (I) over EMA (II), because their operations usually follow the strategy given by corporate management. Behind EMS and EMA, stages III to V utilize EMCS as an efficiency approach because EMCS is a concept of management controls that goes beyond EMS and EMA (Section 2.3). In terms of priority (for stages III to V), firms tend to first prioritize (III) financial performance, because the top priority for firms is to survive in their markets; (IV) environmental performance should be next, and (V) overall performance refers to the combined performance in terms of finance, the environment, and so on. EMCS can be described as analogous to the cleaner production technology for the efficiency approach. Note that because all of EMS, EMA,

and EMCS are within the BAU, this framework does not require firms to go beyond the BAU, unlike the systemic approach.

Meanwhile, "factor" denotes an object (or substance) managed by each stage (or sub-system), such as waste and raw materials. (1) The baseline factor considers general factors not limited to MF (e.g., energy and carbon emissions). The four MF factors are (2) total waste, (3) hazardous waste, (4) raw materials used, and (5) recycled waste. Note that the order of the MF factors (2 to 5) follows the survey results from Thailand (Yagi and Kokubu, 2018). This study supposes that waste reduction (targets 12.5 and 12.3) could be achieved by managing these MF factors in various practices.

Because of the five-by-five matrix, the model from this study consists of 25 potential combinations. To make it easier to understand, this study supposes that a typical path may be from A to H (as eight objectives) in Figure 2. (A) I-1 and II-2 are the baseline of EMS and EMA. (B) I-2 to II-3 are basic waste management, and (C) I-4 and II-4 are basic raw materials management, both of which comply with environmental standards. (D) III-1, IV-1, and V-1 are the baseline of EMCS. (E) III-2 and III-3 are waste management and (F) III-4 is raw materials management, both of which have the goal of improving financial performance by seeking a reduction in costs and profit maximization. (G) IV-2 to V-4 are EMCS both for material efficiency improvement and financial performance (note that both are the potential outcomes of MFCA). (H) I-5 to V-5 are waste recycling management for pollution prevention and corporate capacity.

3.2 The Questionnaire Surveys in Thailand and Vietnam

As an example application (Figure 3), this study compares the listed firms in Thailand and Vietnam in order to reveal any differences in the degree of SCP that is based on economic growth. (As a limitation, however, the two cases are too small to extrapolate to all countries in the world.) This study uses the previous survey from non-financial listed firms in Thailand (Yagi and Kokubu, 2018) and conducts a similar new survey in Vietnam as part of the SCP project (see Supplementary Information A and Tables S10–S11). For the Thailand survey, there were 101 responses (the response rate was 16.9%) among all listed firms in the non-financial sectors as of 2017. Meanwhile, for the Vietnam

survey (translated into Vietnamese), this study received 204 responses in total (the response rate is 29.2%) among all listed firms in the non-financial sectors mostly by December 7, 2018 (Appendix Table A2). Note, importantly, that the high response rate in Vietnam may be because the survey was supported by the Ministry of Natural Resources and Environment, and this support is likely to affect the survey results. For example, the self-rating scores in Vietnam tend to be much better than in Thailand, as seen below.

Out of the total of 20 questionnaire items from Q1 to Q20 (Appendix Table A3), Q1–Q12 were the same as in the previous survey (Yagi and Kokubu, 2018) and Q13–Q20 were not used in the study but were asked in that survey. Regarding Q1–Q12, Q1 asked about the implementation of MF management. Q2–Q5 asked about the actual amounts of total waste, hazardous waste, raw materials consumed, and recycled waste. Q6–Q9 asked about the implementation of research and development (R&D) (Q6), its related expenses (Q7), the implementation of environmental R&D (Q8), and its proportions (Q9). Q10–Q12 asked about the efficiencies of resources (Q10), the amount of waste produced (Q11), and the amount of hazardous waste produced (Q12) according to the Likert scale (1 to 5; larger is better). Regarding Q13–Q20, Q13–Q14, as a baseline, asked about energy consumption (Q13) and carbon (CO_2) emissions (Q14) according to the Likert scale. The other items were the non-financial determinants of MF management (yes/no): capital structure (whether a subsidiary firm or not, in Q15), the business type (e.g., business-to-business [B-to-B] or business to consumer [B-to-C], in Q16), the main market region (e.g., Asia, Europe, North America, or the global market, in Q17), the competitive situation (e.g., whether a monopoly or oligopoly, in Q18), the implementation of EMS (Q19), and the publication of environmental reporting (as EMA) (Q20).

3.3 EMS Stage (I. Strategy and Process)

The following applications in Sections 3.3 to 3.5 follow Yagi and Kokubu (2018) for the most part. The EMS stage (I. strategy and process) tests by using logistic regression analysis whether or not the probability of MF management implementation (p from Q1) is affected by the non-financial factors:

$$\begin{aligned}&\ln\left[p/(1-p)\right]\\&=\beta_0+\beta_1 DumSubsidiary+\beta_2 DumBtoB+\beta_3 DumBtoC+\beta_4 DumAsia\\&+\beta_5 DumEurope+\beta_6 DumNorthAmerica+\beta_7 DumGlobal+\beta_8 DumMonopoly\\&+\beta_9 DumOligopoly+\beta_{10} DumEMS+\sum_j \lambda_j DumMarket_j+\sum_k \gamma_k DumSector_k\end{aligned} \quad (2)$$

where p is the probability of DumQ1=1, and DumQ1 is 1 if MF management (Q1) is implemented and 0 if not.

The crucial explanatory variables in Eq.2 are all dummy variables with the following hypotheses. DumSubsidiary (Q15) is a dummy variable for a subsidiary firm, hypothesizing that a subsidiary would be more likely to implement MF management due to instructions from the parent firm. DumBtoB and DumBtoC (Q16) are dummy variables of B-to-B and B-to-C, hypothesizing that these business types would be more likely to implement MF management. DumAsia, DumEurope, DumNorthAmerica, and DumGlobal (Q17) are dummy variables for the main markets of Asia, Europe, North America, and the global market, hypothesizing that these foreign markets would require a stricter level of MF management than the domestic market (note that DumEurope, DumNorthAmerica, and DumGlobal are omitted for Thailand because of there being too many zeros). DumMonopoly and DumOligopoly (Q18) are dummy variables for monopoly and oligopoly markets (as compared to a competitive market), hypothesizing that firms under perfect competition would not be able to afford MF management. In addition, DumEMS (Q19) is a dummy variable for EMS, under the hypothesis that EMS would encourage the implementation of MF management. Finally, $DumMarket_j$ and $DumSector_k$ are dummy variables for the j-th market (e.g., the stock exchange) and the k-th sector (e.g., the mining sector), respectively, controlling for market and sectorial effects.

3.4 EMA Stage (II. Accounting and Disclosure)

Stage II confirms the publication rate of environmental reports (Q20) (as the baseline) and the disclosure rates of the four MF factors (Q2–Q5). In addition, this stage verifies whether or not MF management (Q1) encourages disclosure by using chi-squared tests.

3.5 EMCS Stage (III to V. Efficiency Approach)

Regarding stage III (the financial performance), as the baseline (1), the cost rate (cost of goods sold [COGS] rate [COGSR]) and return on assets (ROA) are confirmed as profitable. For the MF factors (2–5), the logistic regression tests as to whether financial performance is a hypothetical determinant of MF management (not as its outcome):

$$\ln\left[p/(1-p)\right] = \beta_0 + \beta_1 COGSR + \beta_2 TATR + \beta_3 Leverage + \beta_4 \ln Size + \beta_5 ROA + \beta_6 RDR + \beta_7 EnvRDR + \sum_j \lambda_j DumMarket_j + \sum_k \gamma_k DumSector_k \quad (3)$$

The financial proxy variables are COGSR as cost rate, total asset turnover ratio (TATR; sales divided by total assets) as capital efficiency, leverage, the log of firm size (lnSize) as the size variable, ROA, R&D ratio (RDR; R&D expenses divided by sales), and environmental R&D ratio (EnvRDR; Q9 [%]). The main focus is on COGSR and ROA as the different types of financial performance. Note that while Yagi and Kokubu (2018) used assets per equity as leverage and the log of equity (lnEquity) as lnSize, this study uses debt divided by total assets (DebtR) as leverage and the log of assets (lnAssets) as lnSize, because some firms in Vietnam have negative equity. Moreover, the Vietnam sample omits EnvRDR because it has too many zeros.

Stages IV and V (environmental and overall performance) confirms the following items: efficiencies of energy (Q13) and CO_2 (Q14) as the baseline at stage IV, the amount of total waste (per sales) and its self-rating (Q11), the hazardous waste ratio (hazardous waste divided by total waste [HazR]) and its self-rating (Q12), waste per raw materials (WasteR) and its self-rating (Q10), and the recycled waste ratio (recycled waste divided by total waste [RecR]) as the MF factors at stage IV, and the data envelopment analysis (DEA) score as the baseline at stage V (Supplementary Information B).

In addition, stages IV and V test whether or not MF management (DumQ1) improves both the environmental and overall performance by using t-tests for the self-rating scores (Q10–Q12) and the ordinary least squares (OLS) regression for the objective scores. Specifically, the following OLS model tests whether or not MF management (DumQ1) reduces total waste (lnWaste in log form) by controlling for the market and sectorial effects:

$$\ln Waste = \beta_0 + \beta_1 DumQ1 + \sum_j \lambda_j DumMarket_j + \sum_k \gamma_k DumSector_k + \varepsilon \quad (4)$$

where ε is an error term. Similarly, for the other performance scores, the following OLS model tests whether or not MF management (DumQ1) improves HazR (smaller is better), WasteR (smaller is better), RecR (larger is better), and DEA score (smaller is better) by controlling for the scale of economy (lnWaste) and the market and sectorial effects:

$$\left.\begin{matrix} HazR \\ WasteR \\ RecR \\ DEA\ score \end{matrix}\right\} = \beta_0 + \beta_1 DumQ1 + \beta_2 \ln Waste + \sum_j \lambda_j DumMarket_j + \sum_k \gamma_k DumSector_k + \varepsilon \quad (5)$$

4. Results and Discussion

4.1 Stages I (EMS) and II (EMA)

Table 1 shows the descriptive statistics for the surveys in Thailand and Vietnam (for the survey results, see Appendix Tables A4–A5). Figures 4 and 5 summarize the analytical results for Thailand and Vietnam, respectively. The thick lines show a statistically significant correlation to the implementation of MF management (Q1). Table 2 (column 1 for Thailand and column 2 for Vietnam) shows the regression results for Eq.2. Table 3 indicates the chi-squared test results for Q1 and Q2–Q5.

At stage I, as the baseline factor (Appendix Table A4), EMS (Q19, DumEMS) has been implemented by 61 firms (60%) in Thailand and 76 firms (37%) in Vietnam. In Table 2, the coefficient of DumSubsidiary (Q15) is significantly positive for both Thailand (2.034***) and Vietnam (0.630*); the coefficient of DumBtoB (Q16) is significantly positive for Vietnam (1.410***); and the coefficient of DumMonopoly (Q18) is significantly negative for Vietnam (−1.512**). The results indicate that MF management is more likely to be implemented by subsidiary firms in Thailand and Vietnam, as well as by B-to-B firms and those in non-monopoly markets in Vietnam.

At stage II, as the baseline (Appendix Table A4), environmental reports (Q20, DumEnvReport) have been published by 72% in Thailand (73 firms) and 39% in Vietnam (79 firms). Regarding the disclosure rates, those for total waste (Q2) are 50% in Thailand and 55% in Vietnam; for hazardous waste (Q3), 49% in Thailand and 53% in Vietnam; for the amount of raw materials used

(Q4), 29% in Thailand and 36% in Vietnam; and for the amount of recycled waste (Q5), 24% in Thailand and 32% in Vietnam.

Regarding the chi-squared tests (Table 3), the implementation of MF management (Q1) is (positively) significantly correlated to the disclosure of total waste (Q2), hazardous waste (Q3), and raw materials used (Q4) in Thailand and for Q2, Q3, Q4, and recycled waste (Q5) in Vietnam. The result indicates that MF management encourages MF disclosure, except for the amount of recycled waste in Thailand.

4.2 Stages III, IV and V (EMCS)

Regarding the estimated results, Table 4 shows the logistic regression model in Eq.3. Table 5 indicates the OLS results for Eqs.4–5. Table 6 shows the results of the t-test between Q1 and the self-rating of environmental performance (Q10–Q12).

At stage III, regarding the baseline (1), the average values of COGSR are 74.6% in Thailand and 78.5% in Vietnam, while those of ROA are 7.2% in Thailand and 7.7% in Vietnam (Table 1). In Table 4, the coefficients of COGSR (4.240*) and ROA (8.135*) are significantly positive in Thailand, while that of DebtR (1.689**) is significantly positive in Vietnam, indicating that the significant determinants of MF management are financial performance (COGSR and ROA) in Thailand and leverage in Vietnam.

At stage IV, as the baseline (1), the average energy efficiency (Q13) is 3.646 for Thailand and 4.041 for Vietnam, and the average CO_2 efficiency (Q14) is 3.554 for Thailand and 4.163 for Vietnam (Appendix Table A5). In Table 5 (Eq.5), the coefficient of DumQ1 is significantly negative for HazR in Thailand (−0.221**; Column 3), indicating that MF management improves (reduces) HazR. In Table 6 (t-test), the t-values are statistically significant for Q11 and Q12 in Vietnam, indicating that Vietnamese firms with MF management (Q1) have higher self-rating scores for the total amount of waste (Q11) and amount of hazardous waste (Q12) than for those without it.

Note that, when considering the accuracy of the data, the subjective values from the questionnaire survey depend on self-evaluations. The values for Vietnam may appear unexpected (e.g.,

too large or too good when compared to Thailand), and this is probably because of the Vietnam government's pressure, although this study cannot verify these answers. For example, the average of total waste is 21,368 tons for Thailand and 192,336 tons for Vietnam. Even if one were to take results as a ratio, the waste-per-sales are 170 tons (Thailand) and 7,690 tons (Vietnam) per million USD in the full observations, while those that are less than one thousand (i.e., removing potential outliers) are 14.2 tons (Thailand) and 77.9 tons (Vietnam) tons per million USD.

At stage V, regarding the baseline (1), the average values of DEA scores are 0.367 in Thailand and 0.221 in Vietnam (Table 1). In Table 5, the coefficient of DumQ1 (MF management) is not statistically significant for the DEA score in either Thailand or Vietnam, indicating that MF management does not improve the overall level of efficiency.

4.3 Discussion

Following from the results, firms are more likely to be at stage III (financial performance of EMCS) in Thailand and stages I and II (EMS/EMA) in Vietnam. This suggests that each market (industry) needs its own SCP policy, depending on the rate of economic growth , not a one-size-fits-all policy. In summary, targets 12.4 (via EMS) and 12.6 (via EMA) can be achieved to some extent in both countries, while targets 12.5 (waste) and 12.3 (food losses) can also make progress by means of MF management. However, target 12.2 (via EMCS) seems difficult to achieve.

Vietnamese firms still need support in introducing EMS/EMA because EMS (Q19) and EMA (Q20) were implemented by only 37% and 39%, respectively (compared to 60% and 72% in Thailand). In Vietnam, MF management is more likely to be introduced by the parent company (for a subsidiary; both countries) and in the external environment such as B-to-B business and a competitive situation. Thus, because the motivation to implement EMS/EMA may be for gaining a competitive advantage, SCP policymakers should consider this competition principle while disseminating EMS/EMA.

Note that the Vietnamese firms have a higher self-rating of MF management rate (64%) and disclosure rates (55% for waste, 53% for hazardous waste, 36% for raw material, and 32% for recycled

waste) than Thailand (i.e., 60%, 50%, 49%, 29%, and 24%, respectively), probably because of the Vietnam government's pressure (Section 4.2). Therefore, policymakers should disseminate SCP with objective guidance, rather than relying on corporate self-ratings.

Meanwhile, in Thailand, EMS (60%), EMA (72%), and MF management (58%) have spread to some extent, and EMCS appears to have been introduced slightly (i.e., correlating MF management with the cost rate and profitability). To further disseminate EMCS, there are two options. One is to promote EMS/EMA in a step-by-step fashion as a foundation for EMCS because EMCS is not standardized, unlike EMS/EMA. Another is to support directly the implementation of EMCS in conjunction with MFCA and MCS (Kokubu and Nagasaka, 2019), just as MFCA has been implemented through some initiatives by the Ministry of Economy, Trade, and Industry in Japan (Kokubu and Kitada, 2015) and by the Asian Productivity Organization (2018) in Asian countries. With MFCA and MCS, firms can find inefficient processes to improve as a premise for their efficiency approach.

Regarding the discussion in the academic SCP, certain firms seem to have implemented MF management (both countries) and the efficiency approach (EMCS in Thailand), possibly because the SDGs approach is seen as beneficial to a business (Pedersen, 2018). However, firms still cannot afford to implement the systemic approach (Bengtsson et al., 2018) and cannot be "big D" actors (Scheyvens et al., 2016). The estimation results of this study are part of the SCP scheme (e.g., Lukman et al., 2016; Vergragt et al., 2014, 2016) and the existing SCP policies (e.g., Akenji and Bengtsson, 2014; Brodhag, 2010; Geels et al., 2015; Stevens, 2010). For example, Dobes's (2016) initial review for SCP could be more effective than this study's model in terms of actual business improvement. However, thus far, such evidence for the SCP-via-SDGs approach has not been explicitly derived from the academic SCP. Note that the results of this study partially support Dubey et al. (2016), which argued that top management participation for SCP is affected by normative pressures (e.g., B-to-B business) and mimetic pressures (e.g., market competition) and that information sharing (EMA) and reducing behavioral uncertainty among the stakeholders (e.g., EMS) are important for SCP implementation (MF management).

5. Conclusions

This study proposes an SCP-via-SDGs framework of a five-by-five matrix from the production perspective as the bottom-up approach for individual firms. The five stages are EMS (I. strategy and process), EMA (II. accounting and disclosure), and EMCS (III. financial, IV. environmental, and V. overall performance, as the efficiency approach). The five factors consider the baseline and the four MF factors (total waste, hazardous waste, raw materials used, and recycled waste). Regarding the motivation, JCLP is the leading journal for the study of academic SCP, but the SCP-via-SDGs framework has not been explicitly proposed thus far. Because the SCP-via-SDGs approach is a much narrower concept than the academic SCP, the model for this study may not be academically new but is practical and beneficial to achieve SDGs even for BAU firms.

Following the applications to Thailand and Vietnam, the firms are likely to be at stage III (financial performance of EMCS) in Thailand and stage I or II (EMS or EMA) in Vietnam. This suggests that each market requires individual SCP policies, depending on economic growth. In summary, firms can achieve targets 12.4 (management of chemicals/wastes via EMS), 12.6 (sustainable practice/information via EMA), and 12.5 and 12.3 (reduction of waste and food losses via MF management) to some extent, but it seems more difficult to achieve target 12.2 (resource efficiency via EMCS).

This study has several limitations. First, the framework for this study does not include supply chain management, although this would have been effective and would have created a synergic effect on SCP. Second, the framework does not take the perspective of the systemic approach and those of the government and consumption. Ultimately, the interactions of production, consumption, and the government become important for SCP, although firms may have to go beyond BAU to some extent. Finally, this study does not verify what specific steps firms should take toward SCP. Thus, a future study should focus on finding out those paths toward SCP that are feasible for BAU firms. As this study shows, the road to SCP will be highly dependent on the degree of economic development and on each firm's macro- and micro-environments. Hence it will be necessary to consider not only the external environment but also the internal corporate situation and processes.

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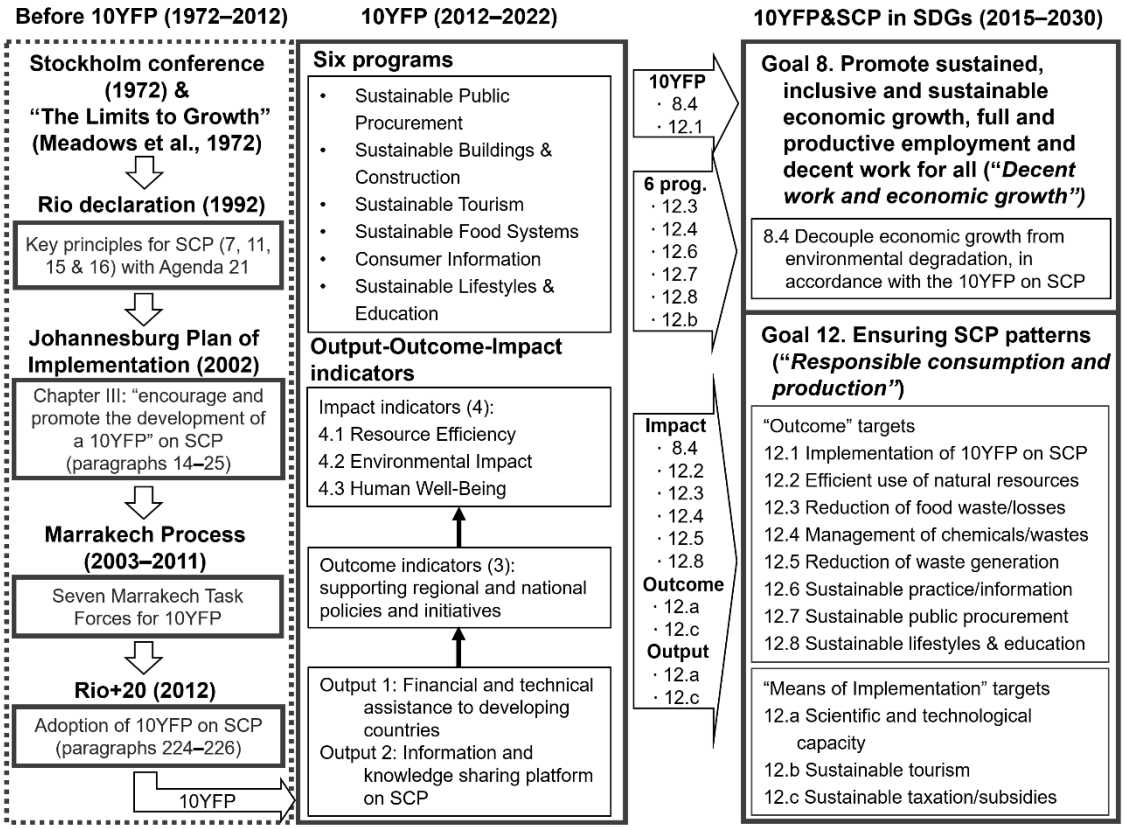

Figure 1. The history of the 10YFP and SCP in SDGs

Notes: Regarding the short history of SCP, the Stockholm conference and the limits to growth (1972) argued for decoupling economic growth from environmental degradation. The Rio declaration (1992) outlined the key principles for SCP. The Johannesburg Plan (2002) called for 10YFP on SCP, and the Marrakesh Process (2003–2011) conducted seven task forces for 10YFP. Afterward, Rio+20 (2012) adopted 10YFP. The 10YFP included six programs, providing for (1&2) output, (3) outcome, and (4) impact indicators. Note that the output, outcome, and impact indicators are based on One Planet network (2018, p. 5, Figure 2) (hence, not on this study). The SDGs consider 10YFP in targets 8.4 and 12.1. Targets 12.3, 12.4, 12.6, 12.7, 12.8, and 12.b are supposed to be based on the six programs. Targets 12.a and 12.c are based on the output and outcome indicators of the 10YFP, while targets 8.4, 12.2, 12.3, 12.4, 12.5, and 12.8 are based on its impact indicators (the arrows are based on our assumptions of this study). See Appendix Table A1 for the targets of SDGs.

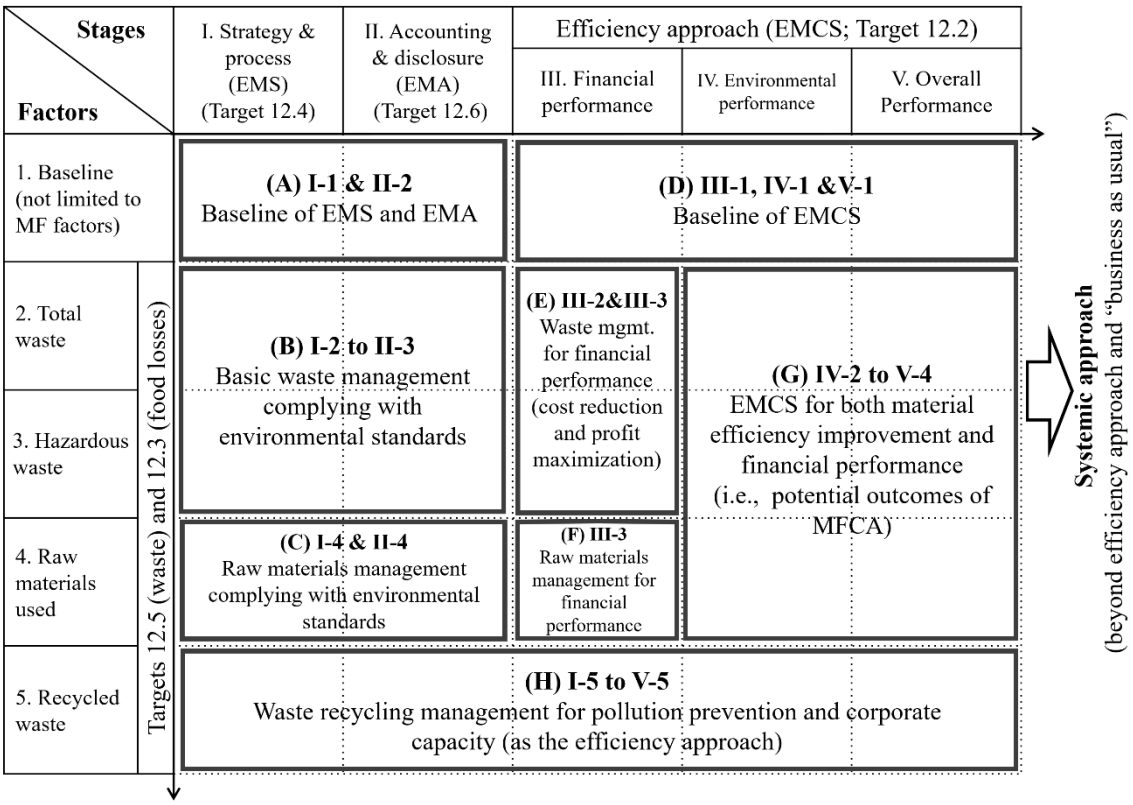

Figure 2. The five-by-five SCP framework from the production perspective

Notes: The SCP framework consists of five stages (I to V) and five factors (1 to 5), and therefore of 25 potential combinations. The five stages come from the literature of corporate environmental management as in Guenther et al. (2016), and the five factors are based on findings in Yagi and Kokubu (2018). A typical path may be from A to H (as eight objectives). (A) I-1 and II-2 are the baseline of EMS and EMA. (B) I-2 to II-3 are basic waste management, and (C) I-4 and II-4 are basic raw materials management, both of which comply with environmental standards. (D) III-1, IV-1, and V-1 are the baseline of EMCS. (E) III-2 and III-3 are waste management and (F) III-4 is raw materials management, both of which have the goal of improving financial performance. (G) IV-2 to V-4 are EMCS both for material efficiency improvement and financial performance (note that both are the potential outcomes of MFCA). (H) I-5 to V-5 are waste recycling management for pollution prevention and corporate capacity.

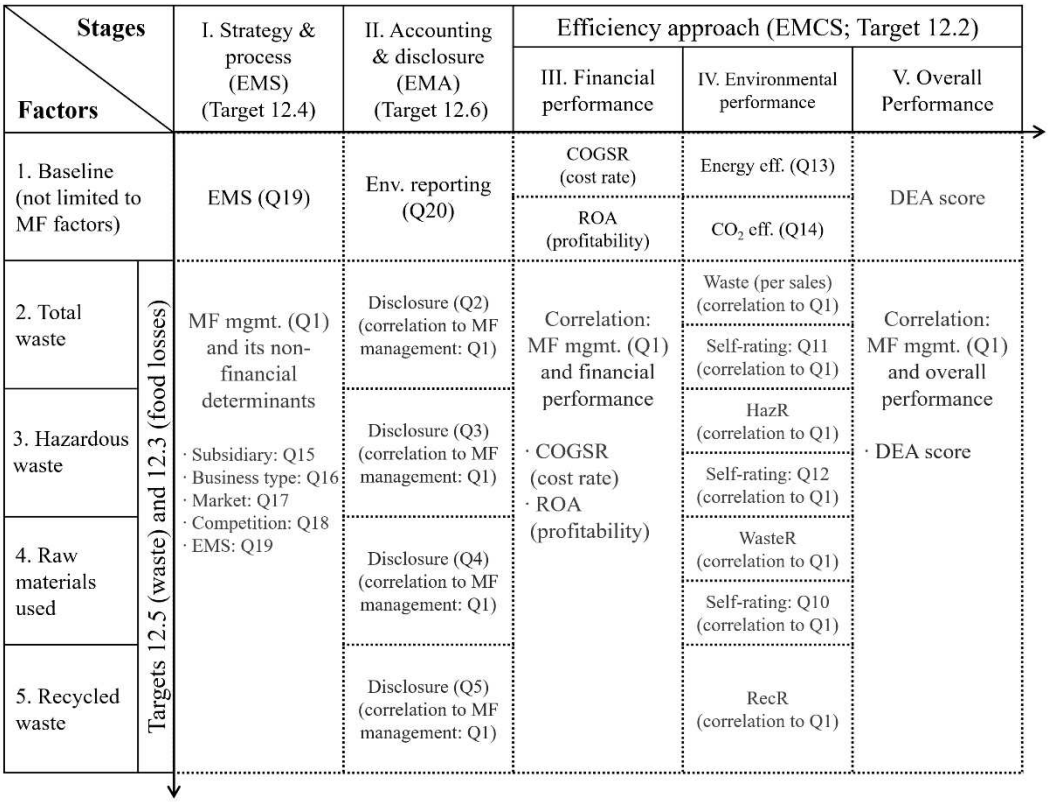

Figure 3. Research strategy of an example application for the SCP framework

Notes: This figure shows the research strategy of this study (Section 4). The five stages come from the literature of corporate environmental management, as discussed in Guenther et al. (2016), and the five factors follow the findings in Yagi and Kokubu (2018). Each cell indicates a focal key variable. Q1 to Q20 are the questionnaire items in Appendix Table A3. This study examines whether companies integrate MF management into EMS, EMA, and EMCS by using some statistical approaches in Section 4.

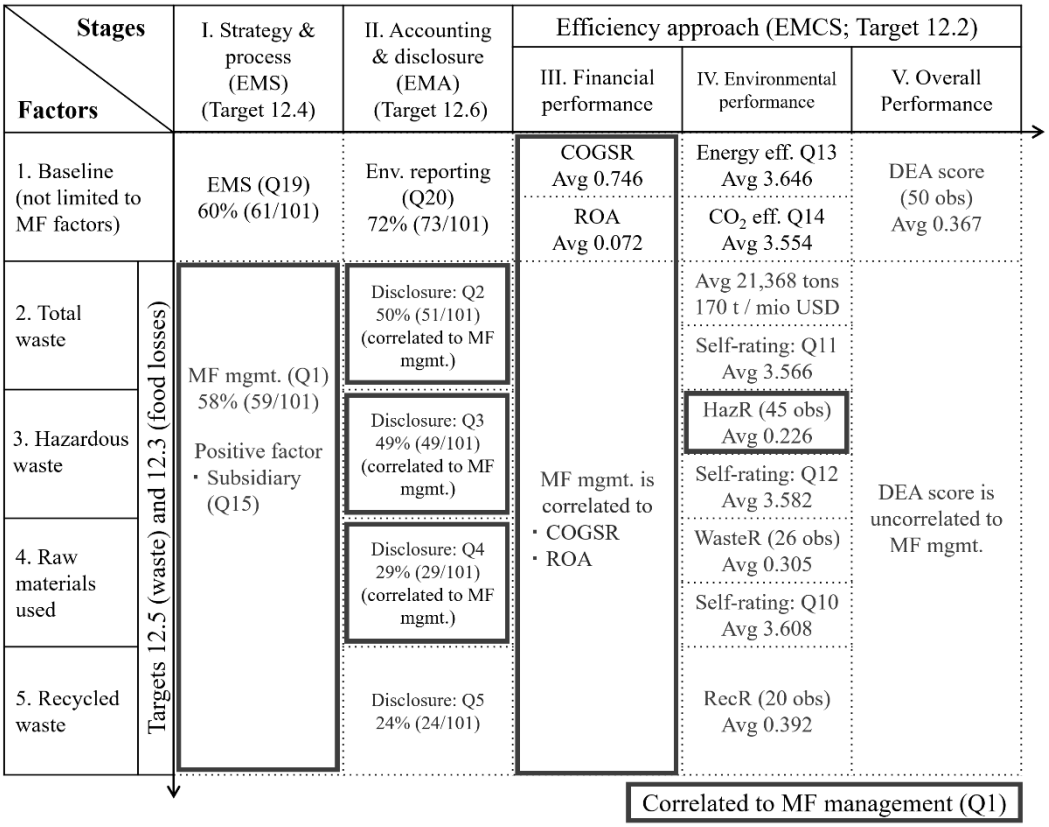

Figure 4. Summary of Thai firms in Yagi and Kokubu (2018)

Notes: This figure shows a summary of the results (Sections 5.1 and 5.2) for Thai firms by using the survey data in Yagi and Kokubu (2018). For average values in each cell, see Table 1. For the statistically significant correlation (i.e., thick lines), see Table 2 for stage I, Table 3 for stage II, Table 4 for stage III, Tables 5 and 6 for stage IV, and Table 5 for stage V.

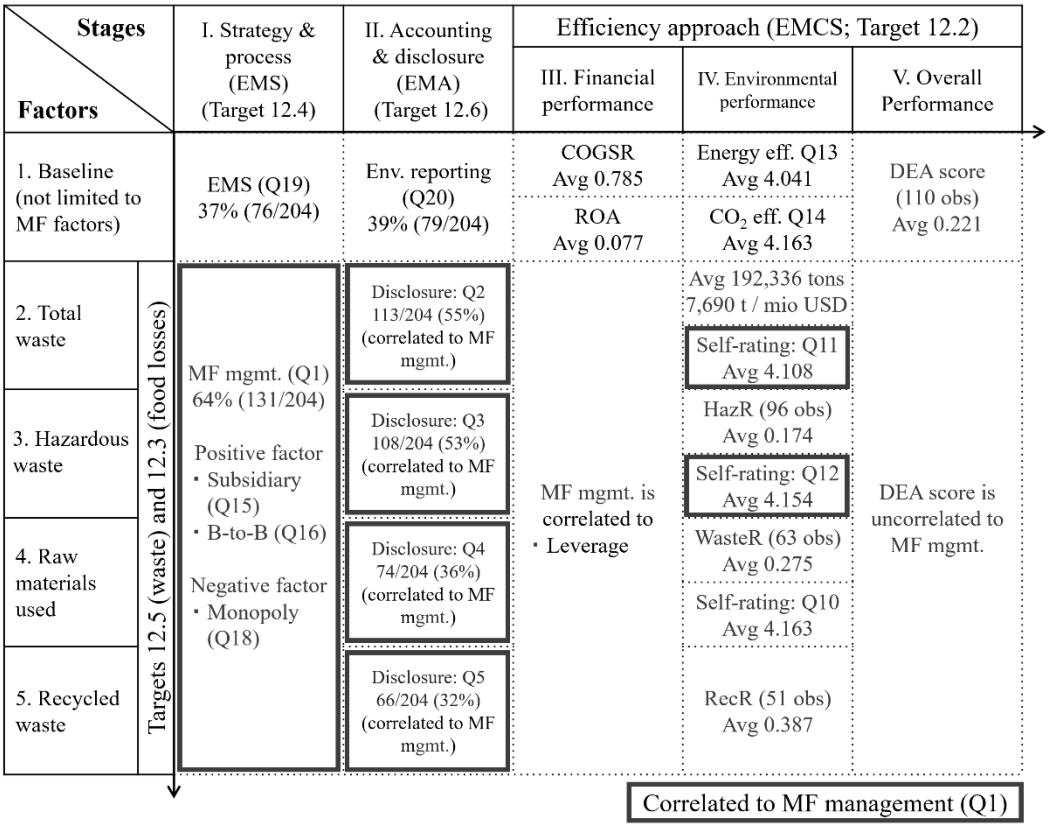

Figure 5. Summary of Vietnamese firms in this study

Notes: This figure shows a summary of the results (Sections 5.1 and 5.2) for Vietnam firms by using the survey data in this study. For average values in each cell, see Table 1. For the statistically significant correlation (i.e., thick lines), see Table 2 for stage I, Table 3 for stage II, Table 4 for stage III, Tables 5 and 6 for stage IV, and Table 5 for stage V.

Table 1. Descriptive statistics for Thailand (Yagi and Kokubu, 2018) and Vietnam (this study)

Variable	Thailand			Vietnam		
	Obs	Average	SD	Obs	Average	SD
DumQ1 (MF management)	99	0.586	0.495	199	0.648	0.479
DumQ2 (waste)	99	0.515	0.502	199	0.563	0.497
DumQ3 (hazardous waste)	99	0.495	0.503	199	0.533	0.500
DumQ4 (raw material)	99	0.293	0.457	199	0.367	0.483
DumQ5 (recycled amount)	99	0.242	0.431	199	0.327	0.470
Financial variables						
COGSR	99	0.746	0.175	199	0.785	0.148
TATR	99	0.890	0.610	199	1.079	0.822
Leverage (Assets per Equity)	99	2.032	1.477	—	—	—
Leverage (DebtR)	—	—	—	199	0.494	0.233
lnEquity (million USD)	99	17.906	1.452	—	—	—
lnAssets (million USD)	—	—	—	199	3.323	1.514
ROA	99	0.072	0.083	199	0.077	0.073
RDR [%]	99	0.070	0.285	199	0.082	0.525
EnvRDR [%]	99	2.525	11.390	—	—	—
Waste performance						
lnWaste (ton)	50	5.598	2.724	110	5.620	4.093
Waste per Sales (ton per million USD; full observations)	51	170.0	1113.3	112	7690.1	40572.9
Waste per Sales (less than 1,000 tons per million USD)	50	14.2	33.1	98	77.9	191.8
WasteR	26	0.305	0.533	63	0.275	0.815
HazR	45	0.226	0.268	96	0.174	0.255
RecR	20	0.392	0.402	51	0.387	0.413
DEA score	50	0.367	0.343	110	0.221	0.252
DumSubsidiary (Q15)	99	0.263	0.442	199	0.397	0.491
DumBtoB (Q16)	99	0.505	0.503	199	0.367	0.483
DumBtoC (Q16)	99	0.283	0.453	199	0.427	0.496
DumAsia (Q17)	99	0.242	0.431	199	0.060	0.239
DumEurope (Q17)	99	0.020	0.141	199	0.035	0.185
DumNorthAmerica (Q17)	—	—	—	199	0.015	0.122
DumGlobal (Q17)	—	—	—	199	0.080	0.273
DumMonopoly (Q18)	99	0.030	0.172	199	0.070	0.256
DumOligopoly (Q18)	99	0.202	0.404	199	0.055	0.229
DumEMS (Q19)	99	0.606	0.491	199	0.372	0.485
DumEnvReport (Q20)	99	0.717	0.453	199	0.387	0.488

Note: Part of the data in Thailand comes from Yagi and Kokubu (2018).

Table 2. Results of the logistic regression models in Eq.2

	1	2
Country	Thailand	Vietnam
Dep. var.	DumQ1	DumQ1
Method	Logit	Logit
	Coef (SE)	Coef (SE)
DumSubsidiary (Q15)	2.034***	0.630*
	(0.711)	(0.370)
DumBtoB (Q16)	0.469	1.410***
	(0.644)	(0.485)
DumBtoC (Q16)	0.231	0.531
	(0.713)	(0.444)
DumAsia (Q17)	0.589	−0.379
	(0.572)	(0.725)
DumEurope (Q17)	—	0.129
	—	(1.223)
DumNorthAmerica (Q17)	—	0.141
	—	(1.504)
DumGlobal (Q17)	—	0.402
	—	(0.736)
DumMonopoly (Q18)	0.654	−1.512**
	(1.391)	(0.744)
DumOligopoly (Q18)	−0.384	−0.507
	(0.603)	(0.765)
DumEMS (Q19)	−0.210	0.036
	(0.522)	(0.393)
Constant	−0.708	−2.058***
	(1.118)	(0.646)
Market dummy	Yes	Yes
Sector dummy	Yes	Yes
Number of obs	99	199
LR chi^2	27.72**	42.92***
Pseudo R^2	0.206	0.166
Log likelihood	−53.297	−107.596

Notes: This table shows the estimated results of logistic regression model. Note that DumEurope, DumNorthAmerica, and DumGlobal are omitted for estimation in Thailand because of too many zeros. 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 statistic for the likelihood ratio chi-squared test, checking whether there is any effect from all independent variables.

Table 3. Chi-squared test of Q1 and MF disclosure (Q2–Q5)

#	Description	Answer	Q1. MF management		Chi-squared	Probability
			Yes	No (or n/a)		
	Thailand (Yagi and Kokubu, 2018)					
Q2	Total waste	Values are disclosed	37	14	8.471***	0.004
		n/a	22	28		
Q3	Hazardous waste	Values are disclosed	36	13	8.878***	0.003
		n/a	23	29		
Q4	Raw materials consumed	Values are disclosed	21	8	3.281*	0.070
		n/a	38	34		
Q5	Recycled waste	Values are disclosed	16	8	0.882	0.348
		n/a	43	34		
	Vietnam (this study)					
Q2	Total waste	Values are disclosed	100	12	67.226***	0.000
		n/a	29	58		
Q3	Hazardous waste	Values are disclosed	91	15	43.971***	0.000
		n/a	38	55		
Q4	Raw materials consumed	Values are disclosed	71	2	53.196***	0.000
		n/a	58	68		
Q5	Recycled waste	Values are disclosed	61	4	35.656***	0.000
		n/a	68	66		

Notes: Upper part is estimation in Thailand (from Yagi and Kokubu, 2018), and lower part is estimation in Vietnam. *** denotes statistically significant level of 1%. Chi-squared tests are based on a degree of freedom of 1.

Table 4. Results of the logistic regression model in Eq.3

	1-	2
Country	Thailand	Vietnam
Dep. var.	DumQ1	DumQ1
Method	Logit	Logit
	Coef (SE)	Coef (SE)
COGSR	4.240*	−1.086
	(2.177)	(1.598)
TATR	−0.203	0.357
	(0.497)	(0.299)
Leverage (Assets per Equity)	0.291	—
	(0.259)	—
Leverage (DebtR)	—	1.689**
	—	(0.838)
lnEquity	0.260	—
	(0.257)	—
lnAssets	—	0.088
	—	(0.128)
ROA	8.135*	2.932
	(4.390)	(3.072)
RDR	−0.021	5.055
	(1.239)	(3.657)
EnvRDR	−0.017	—
	(0.022)	—
Constant	−9.447*	−1.463
	(5.368)	(1.432)
Market dummy	Yes	Yes
Sector dummy	Yes	Yes
Number of obs	99	199
LR chi^2	26.93**	37.48***
Pseudo R^2	0.201	0.145
Log likelihood	−53.688	−110.319

Notes: This table shows the estimated results of logistic regression model. The result for Thailand comes from Yagi and Kokubu (2018, p.772, Table 9). 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 statistic for the likelihood ratio chi-squared test, checking whether there is any effect from all independent variables.

Table 5. Regression results in Eqs.4–5

	1	2	3	4	5
Country	Thailand	Thailand	Thailand	Thailand	Thailand
Dep. var.	lnWaste	WasteR	HazR	RecR	DEA score
	Coef (SE)	Coef (SE)	Coef (SE)	Coef (SE)	Coef (SE)
DumQ1 (MF management)	0.067	−0.262	−0.221**	0.044	−0.008
	(0.904)	(0.258)	(0.093)	(0.219)	(0.122)
lnWaste	—	0.036	−0.040**	−0.033	0.016
	—	(0.061)	(0.017)	(0.063)	(0.021)
Constant	4.657**	0.210	0.696***	0.567	0.010
	(2.050)	(0.713)	(0.215)	(0.516)	(0.294)
Market dummy	Yes	Yes	Yes	Yes	Yes
Sector dummy	Yes	Yes	Yes	Yes	Yes
Number of obs	50	26	45	20	50
F value	1.58	0.74	1.63	0.91	0.73
R^2	0.236	0.257	0.295	0.449	0.141
Adj R^2	0.087	−0.093	0.114	−0.046	−0.053
	6	7	8	9	10
Country	Vietnam	Vietnam	Vietnam	Vietnam	Vietnam
Dep. var.	lnWaste	WasteR	HazR	RecR	DEA score
	Coef (SE)	Coef (SE)	Coef (SE)	Coef (SE)	Coef (SE)
DumQ1 (MF management)	0.577	0.981	−0.057	0.353	0.047
	(1.338)	(0.594)	(0.086)	(0.264)	(0.077)
lnWaste	—	0.011	−0.010	0.016	0.006
	—	(0.030)	(0.007)	(0.013)	(0.006)
Constant	3.341*	−0.929	0.294**	−0.350	0.512***
	(1.984)	(0.731)	(0.129)	(0.370)	(0.116)
Market dummy	Yes	Yes	Yes	Yes	Yes
Sector dummy	Yes	Yes	Yes	Yes	Yes
Number of obs	110	62	96	51	110
F value	0.57	2.06**	1.40	2.91***	1.83*
R^2	0.060	0.312	0.168	0.479	0.184
Adj R^2	−0.045	0.161	0.048	0.314	0.083

Notes: This table shows the estimated results of a regression model (OLS). Columns 2 to 5 come from Yagi and Kokubu (2018, p.773, Table 11). 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 any effect from all independent variables.

Table 6. T-test of Q1 and self-rating environmental performance (Q10 to Q12)

#	Description	Q1. MF management: Yes		Q1. No (or n/a)		t-value	Probability
		Obs	Average (SD)	Obs	Average (SD)		
	Thailand (Yagi and Kokubu, 2018)						
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
	Vietnam (this study)						
Q10	Resource efficiency	129	4.163 (0.788)	67	4.015 (0.807)	−1.235	0.218
Q11	Total waste produced	130	4.108 (0.828)	65	3.846 (0.905)	−2.015	0.045**
Q12	Hazardous waste produced	130	4.154 (0.910)	65	3.877 (0.119)	−1.966	0.051*

Note: This table shows the results of t-test between MF management (Q1) and self-rating environmental performance (Q10 to Q12). ** and * show statistical significance at 5% and 10% levels, respectively.

Appendix Table A1. Goal 12 and target 8.4 of the SDGs

Target	Details
Goal 12	Ensure SCP patterns (short name: “Responsible consumption and production”)
12.1	Implement the 10YEP on SCP Patterns, all countries taking action, with developed countries taking the lead, taking into account the development and capabilities of developing countries (note that six multi-stakeholder programmes of 10YEP are Public Procurement, Buildings & Construction, Tourism, Food Systems, Consumer Information, Lifestyles & Education).
12.2	By 2030, achieve the sustainable management and efficient use of natural resources
12.3	By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses
12.4	By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize their adverse impacts on human health and the environment
12.5	By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse
12.6	Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle
12.7	Promote public procurement practices that are sustainable, in accordance with national policies and priorities
12.8	By 2030, ensure that people everywhere have the relevant information and awareness for sustainable development and lifestyles in harmony with nature
12.a	Support developing countries to strengthen their scientific and technological capacity to move towards more sustainable patterns of consumption and production
12.b	Develop and implement tools to monitor sustainable development impacts for sustainable tourism that creates jobs and promotes local culture and products
12.c	Rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption by removing market distortions, in accordance with national circumstances, including by restructuring taxation and phasing out those harmful subsidies, where they exist, to reflect their environmental impacts, taking fully into account the specific needs and conditions of developing countries and minimizing the possible adverse impacts on their development in a manner that protects the poor and the affected communities
Goal 8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all (short name: “Decent work and economic growth”
8.4	Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10YEP on SCP, with developed countries taking the lead

Notes: Source: UN (2015). See Supplementary Information Table S1 for indicators.

Appendix Table A2. Target and respondent firms

	Total active firms	Target firms (Non-financial firms)	Respondent firms	Response rate
Thailand (Yagi and Kokubu, 2018)				
All firms	663	596	101	16.9%
Market: SET	525	466	78	16.7%
Market: Mai	138	130	23	17.7%
Sector 01: Agro & Food	59	59	8	13.6%
Sector 02: Consumer Products	50	50	8	16.0%
Sector 03: Industrials	124	124	37	29.8%
Sector 04: Property & Construction	112	112	11	9.8%
Sector 05: Resources	60	60	17	28.3%
Sector 06: Services	143	143	15	10.5%
Sector 07: Technology	48	48	5	10.4%
Vietnam (this study)				
All firms	1,568	699	204	29.2%
Market: HOSE	380	169	46	27.2%
Market: HNX	376	156	39	25.0%
Market: UPCoM	812	374	119	31.8%
Sector 01: Mining	61	49	14	28.6%
Sector 02: Wood product	29	25	11	44.0%
Sector 03: Food product	123	108	31	28.7%
Sector 04: Metal and mineral products	113	90	29	32.2%
Sector 05: Machinery and electronic products	59	45	14	31.1%
Sector 06: Pharmaceutical product	82	71	28	39.4%
Sector 07: Other products	111	75	15	20.0%
Sector 08: Utilities	133	93	39	41.9%
Sector 09: Service, construction, and agriculture	784	141	23	16.3%
Sector 10: Finance	73	2	0	0.0%

Appendix Table A3. 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. VND (Vietnamese Dong) / 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)
Q13	Total energy consumption	Likert scale: 1 to 5 (better)
Q14	Total CO_2 and CO_2 equivalents emissions	Likert scale: 1 to 5 (better)
	Other general information	
Q15	Is your firm the subsidiary of a group?	1. Yes / 2. No
Q16	Please describe the type of the business most relevant for your largest business unit.	1. Business to Business (B to B); 2. Business to Consumer (B to C); 3. Business to Government (B to G); 4. More than one selection
Q17	Please describe the currently most important market for your largest business unit.	1. Domestic; 2. Asia; 3. Europe; 4. North America; 5.

		Others; 6. Global
Q18	Please describe the competitive situation on your customer markets for your largest business unit.	1. Monopoly; 2. Oligopoly, 3. Competitive
Q19	Please rate the extent to which your firm has already adopted an environmental management system such as ISO14001 (excluding safety).	1. Yes / 2. No
Q20	Please rate the extent to which your firm has already published an environmental report (including CSR report and sustainability report etc.).	1. Yes / 2. No

Note: Q1–Q12 were the same as in Yagi and Kokubu (2018), and Q13–Q20 were new to this study.

Appendix Table A4. Results of questionnaire survey: binary responses: Q1–Q9, Q15, and Q19–Q20

#	Description	Thailand (101 obs) Yes or disclosure	%	Vietnam (204 obs) Yes or disclosure	%
Q1	MF management (self-rating)	59	58%	131	64%
Q2	Total waste (disclosure)	51	50%	113	55%
Q3	Hazardous waste (disclosure)	49	49%	108	53%
Q4	Raw materials consumed (disclosure)	29	29%	74	36%
Q5	Recycled waste (disclosure)	24	24%	66	32%
Q6	R&D activities (self-rating)	41	41%	43	21%
Q7	R&D expense (disclosure)	25	25%	26	13%
Q8	Environmental R&D activities (self-rating)	23	23%	25	12%
Q9	Environmental R&D proportion (disclosure)	13	13%	15	7%
Q15	Subsidiary of a group	26	26%	81	40%
Q16	Main business type: B-to-B	50	50%	73	36%
Q16	Main business type: B-to-C	30	30%	87	43%
Q17	Most important market: Asia	25	25%	7	3%
Q17	Most important market: Europe	2	2%	3	1%
Q17	Most important market: North America	0	0%	3	1%
Q17	Most important market: Global	20	20%	16	8%
Q18	Competitive situation: monopoly	3	3%	16	8%
Q18	Competitive situation: oligopoly	20	20%	11	5%
Q19	Environmental management system	61	60%	76	37%
Q20	Environmental report	73	72%	79	39%

Notes: For descriptions of the questionnaire items, see Appendix Table A3. The results of items Q1 to Q9 in Thailand come from Yagi and Kokubu (2018).

Appendix Table A5. Results of questionnaire survey: self-rating environmental performance from Q10 to Q14

#		5 (better)	4	3	2	1	No answer	Average score	(SD)
	Thailand in Yagi and Kokubu (2018)								
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)
Q13	Total energy consumption	14	43	37	3	2	2	3.646	(0.837)
Q14	Total CO_2 emissions	16	31	35	8	2	9	3.554	(0.953)
	Vietnam (this study)								
Q10	Resource efficiency	67	89	37	1	2	8	4.112	(0.796)
Q11	Efficiency of waste produced	61	87	40	4	3	9	4.021	(0.861)
Q12	Efficiency of hazardous waste produced	72	79	31	10	3	9	4.062	(0.934)
Q13	Total energy consumption	58	89	45	1	1	10	4.041	(0.774)
Q14	Total CO_2 emissions	74	75	40	0	1	14	4.163	(0.790)

Notes: Upper part is Thailand (from Yagi and Kokubu, 2018), and lower part is Vietnam (this study). For descriptions of the questionnaire items, see Appendix Table A3.

Supplementary Information

- Abbreviations
- Supplementary Information Table S1. Indicators of Goal 12 and target 8.4 of the SDGs (UN, 2015)
- Supplementary Information Table S2. Key principles for SCP in the Rio Declaration (1992) (UN Conference on Environment and Development, 1992)
- Supplementary Information Table S3. III. Changing unsustainable patterns of consumption and production (UN, 2002)
- Supplementary Information Table S4. Marrakech Task Forces (2002–2011) (UNEP, 2011)
- Supplementary Information Table S5. SCP in Rio+20 (2012) (UN, 2012)
- Supplementary Information Table S6. Six multi-stakeholder programs in the 10YFP (2012–2022) (One Planet network, 2018)
- Supplementary Information Table S7. Indicators of success framework for the 10YFP: from outputs 1 and 2 to outcomes to impact (One Planet network, 2018)
- Supplementary Information Table S8. “Sustainable Consumption and Production” in Web of Science core collection until 2019
- Supplementary Information Table S9. Literature review of SCP (34 articles including “sustainable consumption and production” in title)
- Supplementary Information A. Additional information on the survey in Vietnam
- Supplementary Information Table S10. Detailed division information from the survey in Vietnam
- Supplementary Information Table S11. T-tests of five variables for sample selection bias
- Supplementary information B. DEA model

Abbreviations

- ASEAN: Association of Southeast Asian Nations
- BAU: business as usual
- B-to-B: business-to-business
- B-to-C: business-to-consumer
- COGS: cost of goods sold
- COGSR: COGS rate
- DEA: the data envelopment analysis
- DebtR: debt divided by total assets
- EMA: environmental management accounting
- EMCS: environmental management control systems
- EMS: environmental management systems
- EnvRDR: environmental R&D ratio
- EU: European Union
- GDP: gross domestic product
- HazR: the hazardous waste ratio (hazardous waste divided by total waste)
- ISO: International Organization for Standardization
- JCLP: Journal of Cleaner Production
- MCS: Management control systems
- MF: material flow
- MFCA: material flow cost accounting
- MoI: means of implementation
- OLS: ordinary least squares
- RDR: research and development (R&D) ratio
- RecR: recycled waste ratio (recycled waste divided by total waste)
- ROA: return on assets
- R&D: research and development
- SCP: sustainable consumption and production
- SDGs: sustainable development goals
- SPP: sustainable public procurement
- UN: United Nations
- UNEP: UN Environment Programme
- USD: US dollars
- TATR: total asset turnover ratio
- WasteR: waste per raw materials
- 10YFP: 10-Year Framework of Programmes

Supplementary Information Table S1. Indicators of Goal 12 and target 8.4 of the SDGs (UN, 2015)

Indicator	Details
12.1.1	Number of countries with SCP national action plans or SCP mainstreamed as a priority or a target into national policies
12.2.1	Material footprint, material footprint per capita, and material footprint per GDP
12.2.2	Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP
12.3.1	Reported online Global food loss index
12.4.1	Number of parties to international multilateral environmental agreements on hazardous waste, and other chemicals that meet their commitments and obligations in transmitting information as required by each relevant agreement
12.4.2	Hazardous waste generated per capita and proportion of hazardous waste treated, by type of treatment
12.5.1	National recycling rate, tons of material recycled
12.6.1	Number of companies publishing sustainability reports
12.7.1	Number of countries implementing sustainable public procurement policies and action plans
12.8.1	Extent to which (i) global citizenship education and (ii) education for sustainable development (including climate change education) are mainstreamed in (a) national education policies; (b) curricula; (c) teacher education; and (d) student assessment
12.a.1	Amount of support to developing countries on research and development for SCP and environmentally sound technologies
12.b.1	Number of sustainable tourism strategies or policies and implemented action plans with agreed monitoring and evaluation tools
12.c.1	Amount of fossil-fuel subsidies per unit of GDP (production and consumption) and as a proportion of total national expenditure on fossil fuels
8.4.1	Material footprint, material footprint per capita, and material footprint per GDP
8.4.2	Domestic material consumption, domestic material consumption per capita, and domestic material consumption per GDP

Supplementary Information Table S2. Key principles for SCP in the Rio Declaration (1992) (UN Conference on Environment and Development, 1992)

Principle	Details
7	States shall co-operate in a spirit of global partnership to conserve, protect and restore the health and integrity of the Earth's ecosystem. In view of the different contributions to global environmental degradation, States have common but differentiated responsibilities. The developed countries acknowledge the responsibility that they bear in the international pursuit of sustainable development in view of the pressures their societies place on the global environment and of the technologies and financial resources they command.
11	States shall enact effective environmental legislation. Environmental standards, management objectives and priorities should reflect the environmental and developmental context to which they apply. Standards applied by some countries may be inappropriate and of unwarranted economic and social cost to other countries, in particular developing countries.
15	In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.
16	National authorities should endeavour to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment.

Supplementary Information Table S3. III. Changing unsustainable patterns of consumption and production (UN, 2002)

Paragraph	Details
14	Fundamental changes in the way societies produce and consume are indispensable for achieving global sustainable development. All countries should promote sustainable consumption and production patterns, with the developed countries taking the lead and with all countries benefiting from the process, taking into account the Rio principles, including, inter alia, the principle of common but differentiated responsibilities as set out in principle 7 of the Rio Declaration on Environment and Development. Governments, relevant international organizations, the private sector and all major groups should play an active role in changing unsustainable consumption and production patterns. This would include the actions at all levels set out below.
15	Encourage and promote the development of a 10-year framework of programmes in support of regional and national initiatives to accelerate the shift towards sustainable consumption and production to promote social and economic development within the carrying capacity of ecosystems by addressing and, where appropriate, delinking economic growth and environmental degradation through improving efficiency and sustainability in the use of resources and production processes and reducing resource degradation, pollution and waste. All countries should take action, with developed countries taking the lead, taking into account the development needs and capabilities of developing countries, through mobilization, from all sources, of financial and technical assistance and capacity-building for developing countries. This would require actions at all levels to: (a) Identify specific activities, tools, policies, measures and monitoring and assessment mechanisms, including, where appropriate, life-cycle analysis and national indicators for measuring progress, bearing in mind that standards applied by some countries may be inappropriate and of unwarranted economic and social cost to other countries, in particular developing countries; (b) Adopt and implement policies and measures aimed at promoting sustainable patterns of production and consumption, applying, inter alia, the polluter-pays principle described in principle 16 of the Rio Declaration on Environment and Development; (c) Develop production and consumption policies to improve the products and services provided, while reducing environmental and health impacts, using, where appropriate, science-based approaches, such as life-cycle analysis; (d) Develop awareness-raising programmes on the importance of sustainable production and consumption patterns, particularly among youth and the relevant segments in all countries, especially in developed countries, through, inter alia, education, public and consumer information, advertising and other media, taking into account local, national and regional cultural values; (e) Develop and adopt, where appropriate, on a voluntary basis, effective, transparent, verifiable, non-misleading and non-discriminatory consumer information tools to provide information relating to sustainable consumption and production, including human health and safety aspects. These tools should not be used as disguised trade barriers; (f) Increase eco-efficiency, with financial support from all sources, where mutually agreed, for capacity-building, technology transfer and exchange of technology with developing countries and countries with economies in transition, in cooperation with relevant international organizations.
16	Increase investment in cleaner production and eco-efficiency in all countries through, inter alia, incentives and support schemes and policies directed at establishing appropriate regulatory, financial and legal frameworks. This would include actions at all levels to:

	(a) Establish and support cleaner production programmes and centres and more efficient production methods by providing, inter alia, incentives and capacity- building to assist enterprises, especially small and medium-sized enterprises, particularly in developing countries, in improving productivity and sustainable development; (b) Provide incentives for investment in cleaner production and eco-efficiency in all countries, such as state-financed loans, venture capital, technical assistance and training programmes for small and medium-sized companies while avoiding trade-distorting measures inconsistent with the rules of the World Trade Organization; (c) Collect and disseminate information on cost-effective examples in cleaner production, eco-efficiency and environmental management and promote the exchange of best practices and know-how on environmentally sound technologies between public and private institutions; (d) Provide training programmes to small and medium-sized enterprises on the use of information and communication technologies.
17	Integrate the issue of production and consumption patterns into sustainable development policies, programmes and strategies, including, where applicable, into poverty reduction strategies.
18	Enhance corporate environmental and social responsibility and accountability. This would include actions at all levels to: (a) Encourage industry to improve social and environmental performance through voluntary initiatives, including environmental management systems, codes of conduct, certification and public reporting on environmental and social issues, taking into account such initiatives as the International Organization for Standardization standards and Global Reporting Initiative guidelines on sustainability reporting, bearing in mind principle 11 of the Rio Declaration on Environment and Development; (b) Encourage dialogue between enterprises and the communities in which they operate and other stakeholders; (c) Encourage financial institutions to incorporate sustainable development considerations into their decision-making processes; (d) Develop workplace-based partnerships training and education programmes.
19	Encourage relevant authorities at all levels to take sustainable development considerations into account in decision-making, including on national and local development planning, investment in infrastructure, business development and public procurement. This would include actions at all levels to: (a) Provide support for the development of sustainable development strategies and programmes, including in decision-making on investment in infrastructure and business development; (b) Continue to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the costs of pollution, with due regard to the public interest and without distorting international trade and investment; (c) Promote public procurement policies that encourage development and diffusion of environmentally sound goods and services; (d) Provide capacity-building and training to assist relevant authorities with regard to the implementation of the initiatives listed in the present paragraph; (e) Use environmental impact assessment procedures.
20	Call upon Governments as well as relevant regional and international organizations and other relevant stakeholders to implement, taking into account national and regional specificities and circumstances, the recommendations and conclusions adopted by the Commission on Sustainable Development concerning energy for sustainable development at its ninth session, including the issues and options set out

below, bearing in mind that in view of the different contributions to global environmental degradation, States have common but differentiated responsibilities. This would include actions at all levels to:

(a) Take further action to mobilize the provision of financial resources, technology transfer, capacity-building and the diffusion of environmentally sound technologies according to the recommendations and conclusions of the Commission on Sustainable Development, as contained in section A, paragraph 3, and section D, paragraph 30, of its decision 9/1 on energy for sustainable development;

(b) Integrate energy considerations, including energy efficiency, affordability and accessibility, into socio-economic programmes, especially into policies of major energy-consuming sectors, and into the planning, operation and maintenance of long-lived energy consuming infrastructures, such as the public sector, transport, industry, agriculture, urban land use, tourism and construction sectors;

(c) Develop and disseminate alternative energy technologies with the aim of giving a greater share of the energy mix to renewable energies, improving energy efficiency and greater reliance on advanced energy technologies, including cleaner fossil fuel technologies;

(d) Combine, as appropriate, the increased use of renewable energy resources, more efficient use of energy, greater reliance on advanced energy technologies, including advanced and cleaner fossil fuel technologies, and the sustainable use of traditional energy resources, which could meet the growing need for energy services in the longer term to achieve sustainable development;

(e) Diversify energy supply by developing advanced, cleaner, more efficient, affordable and cost-effective energy technologies, including fossil fuel technologies and renewable energy technologies, hydro included, and their transfer to developing countries on concessional terms as mutually agreed. With a sense of urgency, substantially increase the global share of renewable energy sources with the objective of increasing its contribution to total energy supply, recognizing the role of national and voluntary regional targets as well as initiatives, where they exist, and ensuring that energy policies are supportive to developing countries' efforts to eradicate poverty, and regularly evaluate available data to review progress to this end;

(f) Support efforts, including through provision of financial and technical assistance to developing countries, with the involvement of the private sector, to reduce flaring and venting of gas associated with crude oil production;

(g) Develop and utilize indigenous energy sources and infrastructures for various local uses and promote rural community participation, including local Agenda 21 groups, with the support of the international community, in developing and utilizing renewable energy technologies to meet their daily energy needs to find simple and local solutions;

(h) Establish domestic programmes for energy efficiency, including, as appropriate, by accelerating the deployment of energy efficiency technologies, with the necessary support of the international community;

(i) Accelerate the development, dissemination and deployment of affordable and cleaner energy efficiency and energy conservation technologies, as well as the transfer of such technologies, in particular to developing countries, on favourable terms, including on concessional and preferential terms, as mutually agreed;

(j) Recommend that international financial institutions and other agencies' policies support developing countries, as well as countries with economies in transition, in their own efforts to establish policy and regulatory frameworks which create a level playing field between the following: renewable energy, energy efficiency, advanced energy technologies, including advanced and cleaner fossil fuel technologies, and centralized, distributed and decentralized energy systems;

(k) Promote increased research and development in the field of various energy technologies, including renewable energy, energy efficiency and advanced energy technologies, including advanced and cleaner fossil fuel technologies, both nationally and through international collaboration; strengthen national and regional research and development institutions/centres on reliable, affordable, economically viable, socially acceptable and environmentally sound energy for sustainable development;

(l) Promote networking between centres of excellence on energy for sustainable development, including regional networks, by linking competent centres on energy technologies for sustainable development that could support and promote efforts at capacity-building and technology transfer activities, particularly of developing countries, as well as serve as information clearing houses;

(m) Promote education to provide information for both men and women about available energy sources and technologies;

(n) Utilize financial instruments and mechanisms, in particular the Global Environment Facility, within its mandate, to provide financial resources to developing countries, in particular least developed countries and small island developing States, to meet their capacity needs for training, technical know-how and strengthening national institutions in reliable, affordable, economically viable, socially acceptable and environmentally sound energy, including promoting energy efficiency and conservation, renewable energy and advanced energy technologies, including advanced and cleaner fossil fuel technologies;

(o) Support efforts to improve the functioning, transparency and information about energy markets with respect to both supply and demand, with the aim of achieving greater stability and predictability, and to ensure consumer access to reliable, affordable, economically viable, socially acceptable and environmentally sound energy services;

(p) Policies to reduce market distortions would promote energy systems compatible with sustainable development through the use of improved market signals and by removing market distortions, including restructuring taxation and phasing out harmful subsidies, where they exist, to reflect their environmental impacts, with such policies taking fully into account the specific needs and conditions of developing countries, with the aim of minimizing the possible adverse impacts on their development;

(q) Take action, where appropriate, to phase out subsidies in this area that inhibit sustainable development, taking fully into account the specific conditions and different levels of development of individual countries and considering their adverse effect, particularly on developing countries;

(r) Governments are encouraged to improve the functioning of national energy markets in such a way that they support sustainable development, overcome market barriers and improve accessibility, taking fully into account that such policies should be decided by each country, and that its own characteristics and capabilities and level of development should be considered, especially as reflected in national sustainable development strategies, where they exist;

(s) Strengthen national and regional energy institutions or arrangements for enhancing regional and international cooperation on energy for sustainable development, in particular to assist developing countries in their domestic efforts to provide reliable, affordable, economically viable, socially acceptable and environmentally sound energy services to all sections of their populations;

(t) Countries are urged to develop and implement actions within the framework of the ninth session of the Commission on Sustainable Development, including through public-private partnerships, taking into account the different circumstances of countries, based on lessons learned by Governments, international institutions and stakeholders, including business and industry, in the field of access to energy, including renewable energy and energy-efficiency and advanced energy technologies, including advanced and cleaner fossil fuel technologies;

	(u) Promote cooperation between international and regional institutions and bodies dealing with different aspects of energy for sustainable development within their existing mandate, bearing in mind paragraph 46 (h) of the Programme of Action for the Further Implementation of Agenda 21, strengthening, as appropriate, regional and national activities for the promotion of education and capacity-building regarding energy for sustainable development; (v) Strengthen and facilitate, as appropriate, regional cooperation arrangements for promoting cross-border energy trade, including the interconnection of electricity grids and oil and natural gas pipelines; (w) Strengthen and, where appropriate, facilitate dialogue forums among regional, national and international producers and consumers of energy.
21	Promote an integrated approach to policy-making at the national, regional and local levels for transport services and systems to promote sustainable development, including policies and planning for land use, infrastructure, public transport systems and goods delivery networks, with a view to providing safe, affordable and efficient transportation, increasing energy efficiency, reducing pollution, congestion and adverse health effects and limiting urban sprawl, taking into account national priorities and circumstances. This would include actions at all levels to: (a) Implement transport strategies for sustainable development, reflecting specific regional, national and local conditions, to improve the affordability, efficiency and convenience of transportation as well as urban air quality and health and reduce greenhouse gas emissions, including through the development of better vehicle technologies that are more environmentally sound, affordable and socially acceptable; (b) Promote investment and partnerships for the development of sustainable, energy efficient multi-modal transportation systems, including public mass transportation systems and better transportation systems in rural areas, with technical and financial assistance for developing countries and countries with economies in transition.
22	Prevent and minimize waste and maximize reuse, recycling and use of environmentally friendly alternative materials, with the participation of government authorities and all stakeholders, in order to minimize adverse effects on the environment and improve resource efficiency, with financial, technical and other assistance for developing countries. This would include actions at all levels to: (a) Develop waste management systems, with the highest priority placed on waste prevention and minimization, reuse and recycling, and environmentally sound disposal facilities, including technology to recapture the energy contained in waste, and encourage small-scale waste-recycling initiatives that support urban and rural waste management and provide income-generating opportunities, with international support for developing countries; (b) Promote waste prevention and minimization by encouraging production of reusable consumer goods and biodegradable products and developing the infrastructure required.
23	Renew the commitment, as advanced in Agenda 21, to sound management of chemicals throughout their life cycle and of hazardous wastes for sustainable development as well as for the protection of human health and the environment, inter alia, aiming to achieve, by 2020, that chemicals are used and produced in ways that lead to the minimization of significant adverse effects on human health and the environment, using transparent science-based risk assessment procedures and science-based risk management procedures, taking into account the precautionary approach, as set out in principle 15 of the Rio Declaration on Environment and Development, and support

developing countries in strengthening their capacity for the sound management of chemicals and hazardous wastes by providing technical and financial assistance. This would include actions at all levels to:

(a) Promote the ratification and implementation of relevant international instruments on chemicals and hazardous waste, including the Rotterdam Convention on Prior Informed Consent Procedures for Certain Hazardous Chemicals and Pesticides in International Trade so that it can enter into force by 2003 and the Stockholm Convention on Persistent Organic Pollutants so that it can enter into force by 2004, and encourage and improve coordination as well as supporting developing countries in their implementation;

(b) Further develop a strategic approach to international chemicals management based on the Bahia Declaration and Priorities for Action beyond 2000 of the Intergovernmental Forum on Chemical Safety by 2005, and urge that the United Nations Environment Programme, the Intergovernmental Forum, other international organizations dealing with chemical management and other relevant international organizations and actors closely cooperate in this regard, as appropriate;

(c) Encourage countries to implement the new globally harmonized system for the classification and labelling of chemicals as soon as possible with a view to having the system fully operational by 2008; (d) Encourage partnerships to promote activities aimed at enhancing environmentally sound management of chemicals and hazardous wastes, implementing multilateral environmental agreements, raising awareness of issues relating to chemicals and hazardous waste and encouraging the collection and use of additional scientific data;

(e) Promote efforts to prevent international illegal trafficking of hazardous chemicals and hazardous wastes and to prevent damage resulting from the transboundary movement and disposal of hazardous wastes in a manner consistent with obligations under relevant international instruments, such as the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal;

(f) Encourage development of coherent and integrated information on chemicals, such as through national pollutant release and transfer registers;

(g) Promote reduction of the risks posed by heavy metals that are harmful to human health and the environment, including through a review of relevant studies, such as the United Nations Environment Programme global assessment of mercury and its compounds.

Supplementary Information Table S4. Marrakech Task Forces (2002–2011) (UNEP, 2011)

Seven task forces	Objectives
Sustainable Buildings & Construction (Sector-focused)	The main goal of the Task Force was to encourage the development of innovative local and national policies that will mainstream sustainability in construction, use, maintenance, and renovation of buildings. The priority was to raise awareness of the potential of the public sector to promote energy efficiency, energy savings, access to energy, and use of renewable energy in the built environment.
Sustainable Tourism (Sector-focused)	· To build membership of the Partnership among tourism stakeholders · To stimulate and facilitate networking between members and provide access to information about sustainable tourism · To strengthen, coordinate and encourage the take up and implementation of sustainable tourism policies · To establish, implement and support projects that make tourism more sustainable, independently, jointly with members, or in alliance with other international agencies. · To disseminate the results of successful sustainable tourism projects and apply them elsewhere through adaptation, scaling up and replication.
Sustainable Products (Policy tools and programmes)	The objective of the Task Force was to build international collaboration to raise the efficiency of energy-using products. The aims were to identify the priorities for action, and then stimulate and support the development of international networks and cooperative projects to address these priorities.
Sustainable Public Procurement (Policy tools and programmes)	· Capacity-building for the implementation of sustainable public procurement; · Raising awareness with everyone involved in the procurement process (policy makers, procurers, suppliers, manufacturers); · Furthering more sustainable production methods, resource efficiency, social welfare, better products and services and encouraging innovation and the creation of better work places through public procurement; and · Introducing life-cycle thinking in procurement activities.
Sustainable Lifestyles (Social & behavioural issues)	· To engage, enable and encourage citizens, civil society organisations, the business sector and governments to foster sustainable lifestyles; · To identify and disseminate policy options, case studies and good practices from developed and developing countries through research and pilot projects; and · To provide tools and capacity-building to support the integration of sustainable lifestyles in specific sectors (education, awareness-raising, marketing, business development).
Education for Sustainable Consumption (Social & behavioural issues)	The main objective of the Task Force is to promote the role of formal learning processes in providing knowledge, awareness, and competencies to enable sustainable consumption. The efforts are targeted towards the achievement of three objectives: 1. Mapping, exchanging and networking initiatives and good practices on ESC;

	2. The advancement of ESC in formal curricula; and 3. Approaching ESC as a support to other education, environmental and sustainable development policies (e.g. education for sustainable development, environmental protection, including energy and climate policies, consumer protection).
Cooperation with Africa (Regional-focused)	· Strengthen existing organizational structures and establish new structures to promote SCP in Africa; · Develop and support projects for implementing SCP in Africa; · Support the integration and mainstreaming of environmental education in African schools and universities; · Promote sustainable public procurement through training courses and awareness-raising; and · Support the development and deployment of an African Eco-labelling Mechanism.

Supplementary Information Table S5. SCP in Rio+20 (2012) (UN, 2012)

Paragraph	Details
224	We recall the commitments made in the Rio Declaration on Environment and Development, Agenda 21 and the Johannesburg Plan of Implementation on sustainable consumption and production and, in particular, the request in chapter 3 of the Plan of Implementation to encourage and promote the development of a 10-year framework of programmes. We recognize that fundamental changes in the way societies consume and produce are indispensable for achieving global sustainable development.
225	Countries reaffirm the commitments they have made to phase out harmful and inefficient fossil fuel subsidies that encourage wasteful consumption and undermine sustainable development. We invite others to consider rationalizing inefficient fossil fuel subsidies by removing market distortions, including restructuring taxation and phasing out harmful subsidies, where they exist, to reflect their environmental impacts, with such policies taking fully into account the specific needs and conditions of developing countries, with the aim of minimizing the possible adverse impacts on their development and in a manner that protects the poor and the affected communities.
226	We adopt the 10-year framework of programmes on sustainable consumption and production patterns, as contained in document A/CONF.216/5, and highlight that the programmes included in the 10-year framework are voluntary. We invite the General Assembly, at its sixty-seventh session, to designate a Member State body to take any necessary steps to fully operationalize the framework.

Supplementary Information Table S6. Six multi-stakeholder programs in the 10YFP (2012–2022) (One Planet network, 2018)

Programs	Details
Sustainable Public Procurement	The Sustainable Public Procurement programme aims to build the case for sustainable public procurement (SPP) by improving the knowledge on SPP and elevating its reputation as an effective tool to reduce procurement costs, promote SCP, support greener economies and enable sustainable development. The programme supports the implementation of SPP on the ground by facilitating increased collaboration and better access to capacity-building tools and technical advice from SPP experts.
Sustainable Buildings & Construction	The Sustainable Buildings and Construction programme aims to improve awareness of sustainable construction, share good practices and mainstream sustainable building solutions. The programme works to ensure that all stakeholders involved in the planning, commissioning, design, construction, use, management and decommissioning of buildings have a common understanding and the knowledge, resources and incentives required to create, maintain and use sustainable buildings. The programme launches implementation projects, creates community, and commits global actors to sustainable construction.
Sustainable Tourism	The Sustainable Tourism programme envisions a tourism sector that has globally adopted SCP practices that enhance environmental and social outcomes and improve economic performance. Its mission is to catalyse the shift to sustainability, through evidence-based decision-making, efficiency, innovation, collaboration, monitoring and the adoption of a life-cycle approach for continuous improvement. Through the development and implementation of activities, projects and good practices in resource efficient and low-carbon tourism, the programme steers the tourism sector towards enhanced sustainability by reducing the loss of biodiversity, and preserving ecosystems and cultural heritage, while advancing poverty alleviation and supporting sustainable livelihoods.
Sustainable Food Systems	The Sustainable Food Systems programme aims to accelerate the shift towards sustainable food systems, through collaborative initiatives at different levels. The programme addresses global challenges with a holistic, system-based approach towards more integrated and inclusive policy-making. The initiatives of the programme promote awareness raising activities, strengthen capacities, and increase access to knowledge and tools. Areas of focus include sustainable diets, food loss and waste reduction, sustainable value chains and resilient food production systems.
Consumer Information	The Consumer Information programme serves as a global platform to support the provision of quality information on goods and services and the identification and implementation of the most effective strategies to engage consumers in sustainable consumption. It empowers and raises the profile of relevant policies, strategies, projects and partnerships, building synergies and cooperation between different stakeholders to leverage resources towards three main objectives: improving availability, accessibility and quality of consumer information; driving change in government and business; and enhancing communication to drive behaviour change.
Sustainable Lifestyles & Education	The Sustainable Lifestyles and Education programme is committed to shaping, developing and replicating sustainable lifestyles, including low carbon lifestyles. The programme is focused on promoting innovative models and traditional practices consistent with sustainable lifestyles by supporting conducive policies, infrastructure and economic instruments, and encouraging responsible market innovation. Education for sustainable lifestyles is supported by mainstreaming the topic into formal education and learning environments. The programme strives to empower youth and aims to transform current lifestyles and shape those of future generations through sustainable lifestyle scenarios, frameworks and tools.

Supplementary Information Table S7. Indicators of success framework for the 10YFP: from outputs 1 and 2 to outcomes to impact (One Planet network, 2018)

Domain	Details
Outputs 1	・ Support capacity building and facilitate access to financial and technical assistance to developing countries ・ Indicators: 1.1 SCP Projects; 1.2 Financing the shift to SCP; and 1.3 Training for SCP
Outputs 2	・ Serve as an information and knowledge sharing platform on SCP to enable all stakeholders to exchange and cooperate ・ Indicators: 2.1 SCP network; 2.2 Outreach and communication for SCP; and 2.3 Production of SCP knowledge and technical tools
Outcomes	・ Accelerate the shift towards SCP in all countries by supporting regional and national policies and initiatives ・ Indicators: 3.1 SCP in policy instruments; 3.2 SCP monitoring and reporting; 3.3 Education on SCP; 3.4 SCP changes in practices; 3.5 SCP commitments; 3.6 Coordination on SCP; and 3.7 Use of SCP knowledge and technical tools
Impact	・ Increase resource efficiency and decouple economic growth from environmental degradation, creating decent jobs and contributing to poverty eradication and shared prosperity ・ Indicator 4.1 Resource Efficiency (Material use efficiency; Waste reduction; Water use efficiency; and Energy use efficiency) ・ Indicator 4.2 Environmental Impact (GHG emissions reduction; Reduction of air, soil and water pollutants; and Biodiversity conservation and sustainable land-use) ・ Indicator 4.3 Human Well-Being (Gender; Decent work; and Health)

Supplementary Information Table S8. “Sustainable Consumption and Production” in Web of Science core collection until 2019

Search	Doc. types	#	Top 3 journals	Top 3 fields
Topic	All papers	235	JCLP (62), Natural Resources Forum (20), and Sustainability (13)	Environmental Sciences (149), Green Sustainable Science Technology (103), and Engineering Environmental (92)
	Articles in all fields	191	JCLP (54), Sustainability (12), and Resources Conservation and Recycling (8)	Environmental Sciences (113), Green Sustainable Science Technology (85), and Engineering Environmental (74)
	Articles in Environmental Sciences	113	JCLP (54), Sustainability (12), and Resources Conservation and Recycling (8)	--
Title	All papers	86	JCLP (26), Natural Resources Forum (17), and Journal for European Environmental Planning Law (4)	Environmental Sciences (61), Green Sustainable Science Technology (37), and Engineering Environmental (36)
	Articles in all fields	54	JCLP (19), Journal for European Environmental Planning Law (4), and Natural Resources Forum (3)	Environmental Sciences (33), Green Sustainable Science Technology (24), and Engineering Environmental (23)
	Articles in Environmental Sciences	33	JCLP (19), Natural Resources Forum (3), International Journal of Life Cycle Assessment (2), Resources Conservation and Recycling (2), and Sustainability (2)	--

Notes: This table shows search results for the keyword “sustainable consumption and production” in Web of Science (Core Collection covered from 1990 to 2019) provided by Clarivate Analytics (Philadelphia, U.S.). The topic and title searches are conducted, and the results are further divided into (1) all document types in all fields (235 and 86 documents), (2) peer-reviewed articles in all fields (191 and 54 documents), and (3) peer-reviewed articles in “Environmental Sciences” (113 and 33 documents).

Supplementary Information Table S9. Literature review of SCP (34 articles including "sustainable consumption and production" in title)

#	Articles	Details
		[Government perspective: research schemes for SCP]
1	Lukman et al. (2016; JCLP)	・ Review of the sustainability terminology system (from the European perspective [EU]): (1) Sustainable systems (3 terms: responsible care; SCP; and smart city); (2) Sub-systems (9 terms: circular economy; environmental engineering; environmental management strategy; industrial ecology; integrated pollution prevention and control; environmental technology; product service system; pollution prevention; and smart specialization); (3) approaches (10 terms: cleaner production; eco-design; environmental legalization; green chemistry; life cycle assessment; pollution control; supply chain management; voluntary environmental agreement; waste minimization; and zero waste); (4) principles (22 terms: degradation; environmental accounting; ethical investment; education for sustainable development; factor X; health and safety; mutualism; minimization of resource usage; purification; "polluter pays" principle; reporting to the stakeholders; recycling; resource efficiency; remanufacturing; regeneration; repair; reuse; recovery; renewable resources; sustainable production; source reduction; and social responsibility); and (5) other two terms (in notes): policy; and sustainable development.
2	Vergragt et al. (2014; JCLP)	・ Review of the four research frameworks (consumption and production systems; sectors, policies, and impacts; socio-technical transitions; and mainstreaming sustainable consumption) ・ 11 enabling mechanisms (produce with less; green supply chains; co-design produce responsibly; service rather than sell; certify and label; trade fairly; market ethically; buy responsibly; use less; and increase wisely) ・ 9 main research areas (systemic change; macro approaches; production, technology, design; business, innovation, and marketing; governance, policies, politics; civil society; equity; final consumption; and mapping progress).
3	Vergragt et al. (2016; JCLP)	・ Review of technological and social innovations in sustainable life styles ・ In selected 40 papers, 10 different themes: Conceptual Explorations; Sustainable Cities and Governance; Sharing, Grassroots Innovations and Consumer Activism; Behavioral Change; Consumer Values; Food; Energy; Waste; Corporations and Production; and Indicators
		[Government perspective: policy tools for SCP]
4	Brodhag (2010)	・ Review of different political tools at the three layers: everyday life, market economy and global capitalism
5	Stevens (2010)	・ Review of the government roles for SCP ・ (1) Correcting market failures (e.g., through taxes on and subsidies to consumers; and through regulating producers) ・ (2) Correcting systems failures (e.g., through supporting voluntary labelling schemes and mounting general education and communications programmes; and through mandatory labelling, corporate reporting requirements, and certifying the reliability of company claims)
6	Geels et al. (2015)	・ Review of SCP positions: "reformist," "revolutionary," and "reconfiguration"
7	Akenji and Bengtsson	・ Review of SCP policies in the SDGs framework

	(2014)	· Two possible options: SCP as a stand-alone goal and a cross-cutting objective
8	Sakao (2019)	· Model for reviewing SCP research series · "Research Series Review": an approach to capture and analyze a research series for transdisciplinary assessment in qualitative and quantitative terms
9	De Camillis and Goralczyk (2013)	· Developing new market based instruments based on value added tax (VAT) and life cycle thinking (in the EU policy framework)
		[Government perspective: case studies of SCP]
10	Clark (2007; JCLP)	· Review of UNEP activities (such as 10YFP) and tools at the local level (as the global policy on SCP)
11	De Camillis et al. (2012)	· Review of the workshop held in the European Commission's Joint Research Centre site in Ispra, Italy (July, 2011)
12	Tukker et al. (2008; JCLP)	· Review of the Sustainable Consumption Research Exchange network (SCORE!) (which is funded by the EU's sixth Framework Program)
13	Nash (2009; JCLP)	· Review of the European Commission's Communication on the SCP and sustainable industrial policy action plan (introduced on July 16, 2008)
14	Dendler (2014; JCLP)	· Review of four existing product labelling schemes in EU (EU ecolabel, EU energy label, Marine Stewardship Council and Fairtrade label)
15	Liobikienė and Dagiliūtė (2016)	· Estimation of carbon footprints in 25 EU countries (1993-2010)
16	Berg and Hukkinen (2011a; JCLP)	· Case study of the Finnish national SCP programmes (scripted, deliberative, political, ritual, and unprompted)
17	Berg and Hukkinen (2011b)	· Case study: narrative policy analysis of interviews with members of Finland's Committee on SCP
18	Honkasalo (2011; JCLP)	· Review of the Finnish approach for SCP
19	Brizga et al. (2014; JCLP)	· Case study of SCP situations and policies in the post-Soviet republics (9 countries; 1990–2010) · Data (1990-2010); household consumption expenditure, food production index, CO2 emission, electric power consumption, GDP per capita, total materials extraction, and ecological footprint
20	Jonkutė and Staniškis (2019)	· The SCP survey for the representatives of consumers and companies of Lithuania · 384 consumer and 196 enterprise respondents in Lithuania (from May to December, 2012)
21	Tseng et al. (2013; JCLP)	· Case study of SCP practices in Asia (Japan, China, Vietnam, etc.)
22	Zhao and Schroeder (2010)	· Case study of urban lifestyles in Asian developing countries (e.g., China, Indonesia, Japan, South Korea, and Thailand)
23	Schroeder (2014; JCLP)	· Case study of SCP in China · Examining the effectiveness of governance approaches for SCP, by using a four quadrants analysis framework (consumption, production, top-down, and bottom-up)

		[Consumption perspective]
24	Ülkü and Hsuan (2017; JCLP)	・ Modeling of a green consumer's decision making for two competing products (modular and standard products)
25	Cohen and Muñoz (2016; JCLP)	・ Review of sharing economy activities in Sharing Cities-SCP Typology (integrating SCP and private/public orientation)
26	Ma et al. (2019; JCLP)	・ Case study of sharing mobility businesses in China ・ A bike-sharing scheme (Mobike) and an electric-vehicle-sharing scheme (EVCARD)
27	Schroeder et al. (2019; JCLP)	・ Case study on SCP in cities: Shareable.net (San Francisco, U.S.), FEAST project (Sustainable food systems in Kyoto, Japan), and the SWaCH Cooperative (Solid Waste Collection and Handling in Pune, India)
		[Production perspective]
28	Dobes (2016; JCLP)	・ Case study in 57 Czech companies ・ Testing a new integrated diagnostic tool of "Initial Review for SCP" in 57 companies (in Czech Republic during 20082012)
29	Dubey et al. (2016)	・ Case study of Indian organizations (obs: 167) ・ Examining the role of top management beliefs and participation for SCP
30	Dubey et al. (2018; JCLP)	・ Model to examine collaborative performance via big data and predictive analytics (BDPA) in a supply chain ・ A sample of 190 respondents working in auto-components manufacturing organizations in India
31	Lehtoranta et al. (2011; JCLP)	・ Case study of a Finnish pulp and paper mill from the perspective of industrial ecology (industrial symbioses and eco-industrial parks)
32	Luthra et al. (2017)	・ Modeling for SCP evaluation in the supply chain under uncertain environments ・ The grey based Decision Making Trial and Evaluation Laboratory (DEMATEL) technique
33	Mangla et al. (2017; JCLP)	・ Modeling for barriers of SCP in supply chain ・ Case study of Indian automotive business organization ・ The fuzzy Analytical Hierarchy Process for SCP barriers in supply chain
34	Mungkung et al. (2012)	・ Case study of SCP in Thailand ・ Carbon footprint estimation of Canned tuna in sunflower oil and frozen chicken snack using a method of Publicly Available Specification 2050: 2008

Note: The title of Vergragt et al. (2014) includes "sustainable production, consumption."

Supplementary Information A. Additional information on the survey in Vietnam

For the Thailand survey, there were 101 responses (the response rate was 16.9%) among all listed firms in non-financial sectors as of 2017. Meanwhile, for the Vietnam survey (translated into Vietnamese), this study identified 1,568 active firms from the website of Vietstock (provided by Tai Viet Corporation, Vietnam) as of 5 September 2018, and randomly chose 699 non-financial firms (albeit mistakenly including two financial firms) (see Appendix Table A2). This study sent out questionnaires to all 699 non-financial firms. It received 130 responses from companies during the period from October 15 to 30, 2018. Then, this study contacted companies on the list during the period from October 27 to November 30 and collected 74 additional responses through phone calls and email. Most activities finished on December 7, 2018, and this study received 204 responses in total (the response rate was 29.2%). Note, importantly, that the high response rate in Vietnam may be because our survey was supported by the Ministry of Natural Resources and Environment.

In terms of markets, there are three stock exchanges in Vietnam: the Ho Chi Minh Stock Exchange (HOSE), Hanoi Stock Exchange (HNX), and Unlisted Public Company Market (UPCoM) on HNX. Of the 204 firms that responded to this survey, 46 were on HOSE, 39 on HNX, and 119 on UPCoM. Regarding sectors, industry classification was based on the 2007 North American Industry Classification System (NAICS2007) from Vietstock. We divided companies into 10 sectors: #1 mining (14); #2 wood products (11); #3 food products (31); #4 metal and mineral products (29); #5 machinery and electronic products (14); #6 pharmaceutical products (28); #7 other products (15); #8 utilities (39); #9 service, construction, and agriculture (23); #10 finance (no responses). #2 to #7 were manufacturing sectors, and #1, #8, #9, and #10 were non-manufacturing sectors.

In addition, regarding respondents' positions, the 204 responses were from 29 chief executive officers (or members of the top management team), 37 heads/chiefs of environmental or sustainability management, 6 heads/chiefs of operations, and 132 other (subordinate) positions. Regarding respondents' divisions, of the 204 responses, 62 were from the environment, health, and/or safety division, 39 from the administrative division or general managers, 35 from the scientific and

technical division, 10 from the investment or planning division, and 4 from the sales division, and 54 were anonymous (see Supplementary Information Table S10).

Of the 204 respondent firms, this study obtained 2017 financial data for 199 sample firms from the Bloomberg Professional Service (185 firms) and Vietstock (14 firms). For the Vietstock data, this study used the exchange rate of 22,370.09 Vietnamese Dong/USD as of 2017, taken from the website of the World Bank database. Note that we checked sample selection bias, and there is no significant difference between uncensored and censored firms regarding revenue, cost of goods sold (COGS), earnings before interest and taxes (EBIT), total assets, or total equity (Supplementary Information Table S11).

Supplementary Information Table S10. Detailed division information from the survey in Vietnam

Divisions	Details
62 for environment, health, and/or safety (EHS) division	environmental division (32); EHS division (10); safety techniques and environment division (10); occupational safety division (3); environmental and investment division (3); environmental management division (2); environmental management and occupational safety division (1); and quality, health, safety and environment (QHSE) (1).
39 for administrative division or general managers	administrative division (17); general manager (21); and control division (1).
35 for scientific and technical division	technical division (general, planning, production, safety, or environmental) (29); scientific and technical division (1); knowledge-centered support (1); industrial engineering division (1); electromechanical division (1); material equipment division (1); and material technical planning division (1).
10 for investment or planning division	investment planning division (4); planning - environment division (1); planning - material division (1); planning - technical division (1); planning and administrative division (2); and real estate investment division (1).
4 for sales division	sales division (4)
54 for anonymous division	--

Supplementary Information Table S11. T-tests of five variables for sample selection bias

	Total obs	Censored firms (495)		Uncensored firms (199)		Difference of average	t-value	Probability
		Obs	Average (SD)	Obs	Average (SD)			
Revenue	1,371	1,172	83.747 (352.119)	199	83.435 (287.711)	0.312	0.012	0.991
COGS	1,331	1,132	57.160 (260.264)	199	69.770 (252.301)	−12.610	−0.633	0.527
EBIT	1,351	1,152	5.994 (30.541)	199	8.935 (33.684)	−2.941	−1.235	0.217
Total Assets	1,375	1,175	289.897 (2655.281)	200	111.305 (365.491)	178.592	0.949	0.343
Total Equity	1,375	1,175	241.566 (2510.83)	200	54.533 (165.653)	187.034	1.053	0.293

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

Supplementary information B. 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:

$$\begin{gathered}\text{If } (v^t, w^t) \in P_o^t(x^t) \text{ and } 0 \le \theta \le 1 \text{ then } (\theta v^t, \theta w^t) \in P_o^t(x^t) \\ \text{If } (v^t, w^t) \in P_o^t(x^t) \text{ and } w^t = 0, v^t = 0.\end{gathered} \tag{B.1}$$

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:

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

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:

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

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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