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Carbon Management Accounting Considerations for Corporate Carbon Reduction: The Limitations and Future of Integrating Life Cycle Assessment and Material Flow Cost Accounting

Hamad Alhumoudi[1], Abdullah Abdurhman Alakkas[1*], Soha Khan[2], Ashraf Imam[3], Asif Baig[4], Adam Mohamed Omer[5], Imran Ahmad Khan[6]

[1] Department of Accountancy, College of Administrative and Financial Sciences, Saudi Electronic University, Riyadh 13316, Saudi Arabia
[2] Department of Accounting and Finance, College of Business Administration, Prince Mohammad Bin Fahd University, Al Khobar 31952, Saudi Arabia
[3] Al-Fayha College, Jubail 31961, Saudi Arabia
[4] Jubail Industrial College, Jubail Industrial City, Jubail 35718, Saudi Arabia
[5] Accounting Program, Applied College, Muhyle, King Khalid University, Asir - Abha 61421, Saudi Arabia
[6] S.K. College of Business, Aligarh 202001, India

Corresponding Author Email: a.alakkas@seu.edu.sa

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ABSTRACT

This paper focuses on the integration of Material Flow Cost Accounting (MFCA) and Life Cycle Assessment (LCA) or Carbon Footprint (CFP), a Carbon Management Accounting (CMA) method that can incentivize firms to reduce carbon. A literature review was conducted to identify the decision-making situations and limitations that MFCA and LCA (CFP) integration models can support. Twenty-one previous literatures were collected and three types of MFCA and LCA (CFP) integration methods were identified: collaborative, product-based partial integration, and process-based partial integration. Next, the collected prior literature was analyzed based on the CMA decision-making framework proposed and some issues were identified. The common challenge of the three existing integrated models is that they can only provide short-term and past-oriented information. It is difficult to provide incentives for carbon reduction because it does not show the relationship between the physical information of carbon emissions and the cost information. It is also difficult to encourage management to make long-term decisions on green procurement, capital investment, environmentally conscious product design, etc. Another common issue is that the use of MFCA tends to focus on the carbon emissions of material losses rather than all the carbon emissions carried by materials, which may impede product development and capital investment with zero or low carbon emissions in mind. This may inhibit product development and capital investment in consideration of zero carbon and low carbon emissions. The quality of LCA (CFP) information to support internal corporate decision-making is still lower than that of MFCA. Finally, another issue is how to share the information from MFCA among supply chains to extend the process-based partially integrated model to the supply chain.

1. INTRODUCTION

There is no longer any doubt that global warming is progressing, with an increase of 1.5°C between 2030 and 2050 [1, 2]. In the Global Risks Report 2021 published by the World Economic Forum, risks related to climate change were consecutively ranked in the top five among the risks considered likely to occur in the next decade for the nine years from 2013 to 2021 [3]. This is evidence that managers and national leaders have come to regard climate change issues as extremely important.

The growing seriousness of the climate change problem has heightened society's interest in the issue and strongly encouraged international efforts by countries and companies to significantly reduce carbon emissions. Symbolic among these efforts is the Paris Agreement (Appendix 1), which promotes carbon reductions by each country. In preparation for the Paris Agreement, India has set a target of reducing greenhouse gas (GHG) emissions by 80% by 2050 [4], but other countries and environmental NGOs have called for more aggressive emission targets. International efforts to promote corporate carbon reduction include the "100% Renewable Energy Initiative" (Appendix 2) (Renewable Energy 100%: RE100), which promotes the conversion of all electricity consumed by companies to renewable energy, and the "Science-based Carbon Reduction Targets" initiative, which requires companies to set long-term carbon reduction targets with a scientific basis. The "Science Based Targets Initiative"

(SBTI), which requires companies to set long-term carbon reduction targets with a scientific basis (Appendix 3), is one example.

On the other hand, various efforts to address climate change issues are requiring companies to enhance their disclosure of climate change-related information. Not only environmental NGOs but also investors are increasingly considering the environment when making investments.

Based on the above trends, carbon-intensive fossil fuel assets have become stranded assets (Appendix 4) [5], and external stakeholders such as investors and governments are increasingly putting pressure on companies to reduce carbon emissions. Therefore, companies must manage carbon efficiently and effectively within the company to ensure carbon reduction [6].

Carbon Management Accounting (CMA), the subject of this paper, is seen as a means to successfully manage corporate carbon [7]. Therefore, this paper focuses on CMA methods that contribute to corporate carbon reduction.

CMAs can be defined in various ways, but are most broadly defined as the recognition (voluntary/forced), valuation (monetary/non-monetary), and auditing and reporting of GHG emissions (direct/indirect) for internal corporate purposes [8]. It is expected that CMAs can be used to better manage energy and material flows and support decision-making at all organizational levels to achieve more substantial carbon reductions [7]. Several studies are representative papers that comprehensively review the current state of CMA practice and research [9]. Study [10] conducted an interview survey of 10 German listed companies to elucidate the current status of CMA practices in these companies. They found that CMAs are not efficiently structured in the surveyed companies, that physical information dominates the collection of information on carbon emissions, and that the potential and importance of benefits (reduced costs and increased profits) related to carbon reductions are not fully recognized. Gunarathne et al. [9] collected 31 previous studies of CMAs and, by classifying and organizing this literature, identified the need to link physical information on carbon emissions with monetary information to promote carbon management. Therefore, CMA studies that link monetary and physical carbon information will be necessary to promote carbon emission reductions by firms.

Environmental Management Accounting (EMA), which is the basis of CMA, includes both areas of integrating EMA methods that focus on monetary information and environmental management methods that focus on physical quantity information, and there are previous studies on each [11, 12]. Among the many EMA methods, among them, Material Flow Cost Accounting (MFCA) and Life Cycle Assessment (LCA) or Carbon Footprint (CFP), which are mainly based on physical quantity information, have been integrated. The largest number of studies at present are examining the integration of MFCA with Life Cycle Assessment (LCA) or Carbon Footprint (CFP), which is mainly based on physical quantity information. Not only theoretical studies on the development of such EMA models [13, 14], but also case studies on the introduction to companies [15, 16], and studies on integration of LCA (CFP) and MFCA have already been accumulated. Therefore, this paper conducts a literature review focusing on previous studies examining the integration of LCA (CFP) and MFCA to identify the circumstances under which previous studies of both methods can support decision-making on carbon reduction, the limitations, and future research directions for integrated LCA (CFP) and MFCA models for carbon reduction.

Section 2 describes LCA or CFP, which can provide physical quantity information, and MFCA, which is an EMA method that can provide monetary information on carbon emissions, as environmental management methods applicable to carbon management, and examines the applicability of each method to corporate carbon management and the significance and possibility of their integration. Section 3 describes the analytical framework of this paper and the method of literature collection. Section 4 discusses previous studies of integrated models, clarifies the decision-making situations that existing integrated models can support based on the analytical framework described in Section 3, and clarifies the limitations of previous studies. Finally, Section 5 summarizes this paper and provides directions for future research.

2. ENVIRONMENTAL MANAGEMENT ACCOUNTING METHODS APPLICABLE TO CARBON MANAGEMENT

A representative early study of CMA [10], which focused on the different characteristics of carbon information needed by different departments and managers in a company, and presented a carbon-focused, decision-oriented They present a carbon-focused decision-oriented CMA framework based on the EMA framework [17]. Their proposed CMA framework is shown in Table 1. This framework is based on the following three perspectives: physical and monetary dimensions of management information by attribute; past, present, and future by the timing of information used for decision making; short-term and long-term perspectives by the length of the time frame in which decisions are made; and regular and special-purpose generated information by the routine nature of information provision. Previous studies [9, 10] use the CMA framework to analyze the CMA practices of existing firms and suggest that these firms should be given more carbon emission benefits, they point out that it is necessary to link monetary and physical carbon information and provide incentives to encourage firms to reduce their carbon emissions.

Next, LCA (CFP), a representative method that can provide quantity information, and MFCA, a method that can provide monetary information, are introduced, and the possibility of integrating both methods is discussed.

2.1 Environmental management method based on material quantity information

LCA (CFP) is one important method that can provide quantitative information for environmental management [6, 8]. LCA is defined as "a method for collecting and evaluating the inputs, outputs, and potential environmental impacts of a product system over its entire life cycle" [18]. LCA is a decision support method that can evaluate not only GHGs but also multiple and indirect environmental impacts and provides a basis for making decisions to reduce environmental impacts. It aims to understand and evaluate the scale and significance of potential environmental impacts throughout a product's life cycle and is said to be able to identify which substances are relevant to which environmental issues and to convert all environmental impacts into social costs.

Table 1. CMA framework

		Monetary Unit Carbon Accounting		Quantity Based Carbon Accounting	
		Short-Term Perspective	**Long-Term Perspective**	**Short-Term Perspective**	**Long-Term Perspective**
Past-oriented	Periodically generated information	1. Carbon cost accounting	2. Carbon capital expenditure accounting	3. Carbon flow accounting	4. Carbon Capital Impact accounting
	Information for special purposes	5. Post-valuation of short-term/related carbon costing	6. Ex-post evaluation of carbon reduction investments	7. Post-Effect of Short-Term Carbon Impact	8. Post-valuation of material carbon investment valuation
Future-oriented	Periodically generated information	9. Budgeting of monetary carbon operations	10. Carbon Long-term financial planning	11. Quantity Carbon budget	12. Long-term carbon planning
	Information for special purposes	13. Related carbon cost calculation	14. Investment evaluation of monetary carbon projects	15. Carbon Impact Budget	16. Quantitative environmental investment assessment

(Source: Prepared by the authors based on Burritt et al. [10])

CFP is also based on the LCA methodology and was developed with a focus on carbon emissions [19], the international standard for CFP, CFP is defined as "the sum of GHG emissions and GHG removals in a product system, expressed in carbon equivalents and based on a Life Cycle Assessment using the climate change single impact category" [18]. This approach is expected to play two roles: first, it will contribute to "visualizing" the carbon emissions of a product throughout its life cycle. In other words, it can identify areas of high GHG emissions throughout a product's life cycle and focus carbon reduction efforts there to achieve more effective carbon reduction [20]. The second role of CFP is to display calculated carbon emissions on products, which is expected to appeal to consumers' awareness of carbon reduction and encourage them to purchase products with low carbon emissions [20]. This change in consumer awareness is expected not only to have the recurring effect of encouraging manufacturers to develop products with low carbon emissions but also to make it possible to build a low-carbon society.

Le Breton and Aggeri [8] consider CFP as the main method that can provide physical information on carbon emissions at the product scale. Also, Cordova et al. [6] conducted a review of 31 previous studies on CMA and identified 11 of them as literature focusing on CFP. Therefore, CFP is positioned as a product physical CMA method in one area of CMA, quantifying the carbon emissions of a product throughout its life cycle, explaining whether a business is sustainable in the past and present, and contributing to ensuring transparency of the product itself in terms of carbon.

However, while CFP "visualizes" the physical information of carbon emissions over the entire life cycle of a product, its impact on corporate finance is not subject to evaluation [18]. For these reasons, it is pointed out that CFP remains merely a method to make carbon emissions transparent and is unlikely to lead to concrete carbon reduction actions by companies [21]. Brunelli et al. [22] point out the importance of monetary information as well as physical information on carbon emissions to support the implementation of carbon reductions and the improvement of corporate sustainability. Therefore, integrating LCA (CFP) with methods that can provide monetary information and simultaneously show carbon emissions and costs is expected to promote carbon reduction behavior.

2.2 Environmental management accounting based on monetary information

This section describes MFCA as a method that can provide monetary information on carbon emissions.

The EMA based on monetary information includes MFCA, environmental budget matrix, Life Cycle Costing, etc. but this paper focuses on MFCA for the following two reasons.

The first reason is that MFCA is encouraged as a method that can effectively promote the effective use of resources, including carbon, by making managers pay attention to the efficiency of resource use because it reveals economic losses caused by inefficient resource use more clearly than conventional cost accounting.

Next, Brunelli et al. [22] categorized CMA into two types of calculations: "non-sustainability calculations" and "sustainability calculations," noting that non-sustainability calculations can direct the carbon emission reduction (sustainability improvement) actions of companies. MFCA can evaluate the non-sustainability of resource use (material losses) in physical and monetary units at the same time and thus can not only direct but also encourage effective resource use, including carbon emissions. In other words, MFCA is expected to serve as an incentive to change a company from non-sustainability to sustainability.

The international standard for MFCA, MFCA is defined as "a method for quantifying the flow and stock of materials in a process or production line in physical and monetary units" [19]. This method was developed by B. Wagner in Germany and seeks to reduce both environmental impact and cost, built around the core idea of eco-efficiency (Appendix 5) (eco-efficiency).

MFCA has two roles [19, 23]. The first role is to understand the inefficiencies in the use of resources (materials and energy) of a company by identifying the flow of materials and energy in the manufacturing process in physical quantity and separating the "positive products" that become final products from the "negative products" that do not. The second role is that MFCA is considered to provide management with a basis for understanding material and energy flows in terms of quantity, evaluating each in financial terms, providing an opportunity to improve eco-efficiency by showing both quantity and cost simultaneously and providing an opportunity to improve both environmental and financial performance through a review of past production practices.

However, while MFCA can precisely calculate economic benefits (cost reduction), it only captures environmental impact reduction benefits in terms of physical quantity [24] and does not have a function to convert the physical quantity into carbon emissions. Therefore, MFCA is considered to be able to support carbon management by integrating it with methods that can determine the effect of environmental load reduction (e.g., [24]).

As a result of the above study, it is considered that integrating LCA (CFP) and MFCA can provide both physical and monetary information on carbon emissions and promote the carbon reduction behavior of companies. The following section discusses the significance and potential of integrating the two methods.

2.3 Significance and possibility of LCA (CFP) and MFCA integration

This section discusses the integration of MFCA and LCA (CFP) as a typical method to link quantity and monetary information.

The significance of integrating both methods is that MFCA provides cost information on materials and energy and LCA (CFP) provides carbon emissions at the same time, which may help corporate management recognize carbon reduction opportunities, provide incentives for carbon reduction behavior, and contribute to improving corporate sustainability [25].

The two methods can be integrated in the following respects [24].

- Both methods also calculate material and energy.
- Both methods seek to improve materials and energy.

Furthermore, due to the relevance of both methods in the calculation phase, there are three possible ways to integrate them.

- The first is that both methods are computed separately at the computation stage, and the results of both calculations are related and provided only when making a decision. In this paper, we refer to this as the collaborative approach.
- The second method is based on one of the methods and completely integrates it with the other method from the calculation stage. For example, the CFP-based method uses MFCA to measure costs along the product life cycle (which is the target of CPF calculation). In this paper, this is referred to as the fully integrated method.
- The third method is an integration method other than the above, i.e., a partial integration of the two methods at the calculation stage. This is referred to as partial integration in this paper.

Given that both MFCA and LCA (CFP) methods are considered to be integrated because they share commonality in their objectives and measurement targets, and given that previous studies examining the integration of both methods have been accumulated, this paper reviews previous studies on the integration of both methods and examines the limitations and future ideal of existing integration models to promote carbon reduction.

3. ANALYTICAL METHODOLOGY

3.1 Framework of analysis

The decision-oriented CMA framework mentioned in Section 2 is often used as an analytical framework in the CMA research area. For example, based on the CMA framework, a previous study [10] conducted an interview survey of 10 German listed companies to elucidate the current state of CMA practices in the surveyed companies. Another study [6] compared 31 previous CMA studies based on the above CMA framework and clarified the issues of existing CMA studies. Based on the CMA framework, another study [26] also interviewed five electric utilities in New Zealand to identify differences in the adoption of climate change strategies and CMAs when facing different climate change risks and opportunities. Among them, studies [6, 10] use the CMA framework to clarify the current status and identify issues in previous studies. In this paper, similarly, it is appropriate to use the CMA framework [10, 17] as an analytical framework to clarify the current state of decision-making information and extract issues to which the integrated model considered in the previous studies can contribute.

3.2 Methods of literature collection

In this paper, we collected 21 previous studies examining the integration of MFCA and LCA (CFP) in India and overseas by June 2023. The method of literature collection was based on a previous study [6]. The literature was collected from "Google Scholar," "EBSCO," "JSTOR," and "Web of Science". Since there are few references reviewing the integration of MFCA and LCA (CFP), the search keywords are MFCA, LCA, CFP, Material Flow Cost Accounting, Life Cycle Assessment, and Carbon Footprint, referring to the respective international standards. The work papers and conference papers are excluded. The MFCA and LCA (CFP) were excluded if they were not examined simultaneously [27].

4. ANALYSIS RESULTS

4.1 Definition and structure of existing integrated models

As a result of the analysis, it was possible to identify 21 previous studies, among which there were three types of integration methods of MFCA and LCA (CFP). Specifically, the linkage type and the partial integration type were identified, and for the partial integration type, two types, product-based and process-based partial integration types, were identified depending on the target of measurement. Table 2 lists the references belonging to the three integration methods identified in this way. The definitions, structures, and roles of the three integration types are described below. Note that this table excludes the paper [24] that examines one or more integration methods of MFCA and LCA (CFP).

Table 2. Literature corresponding to each MFCA and LCA (CFP) integration type

MFCA and LCA (CFP) Integration Types		Literature
Cooperation type		Bux & Amicarelli, 2022; Zeng, Zhou, & Xiao, 2021; Wagner, 2015; Nyide, 2016; Doorasamy, 2016
Partially integrated	Product-based	Seifbarghy, Hamidi, & Chattinnawat, 2022; Qian, Burritt, & Chen, 2015; Christ & Burritt, 2017
	Process-based	Bresciani et al., 2023; Dekamin & Barmaki, 2019; Ho et al., 2021; Sulong, Sulaiman, & Norhayati, 2015; Guenther et al., 2017; Schmidt, 2015; Fakoya & Imuezerua, 2021; Dekamin, Kheiralipour, & Afshar, 2022; Arieftiara, Theresa & Sari, 2021; Pratt, Lenaghan, & Mitchard, 2016; Dekamin, Kheiralipour, & Afshar, 2022; Pexas et al., 2021

(Source: Prepared by the authors)

(i) Cooperative type

As explained in Section 2, in the collaborative type, both methods, MFCA and LCA (CFP), are not integrated at the calculation stage, but are calculated separately, the obtained information is not linked, and finally, the calculation results of both methods are related and provided when making a decision. The coordinated method consists of MFCA and LCA (CFP). MFCA and LCA (CFP) are calculated separately, with MFCA calculating positive and negative product costs through production line measurements and LCA (CFP) calculating carbon emissions or LCA (CFP) calculates carbon emissions or social costs through the measurement of a product's life cycle. Finally, for example, after the introduction of a new environmentally friendly technology, the LCA (CFP) can be used to measure and clarify the eco-efficiency (change in carbon emissions) and the economic benefits (change in material loss costs) before and after the introduction with MFCA, using a coordinated model.

(ii) Partially integrated

In previous studies, two types of partial integration can be identified, which can be distinguished as product-based partial integration and process-based partial integration, depending on the difference in the computation target. The following sections describe each of the two types of partial integration.

a. Product-based partially integrated type

The product-based partial integration type is a method in which LCA (CFP) is integrated with a part of MFCA. This integrated type consists of LCA (CFP) and a part of MFCA. The LCA (CFP) is used to measure carbon emissions at each stage of the product life cycle (from raw material procurement to disposal), to which is added information on the ratio of positive to negative products based on MFCA, then the carbon emissions of the product are divided into positive and negative according to this ratio, and finally cost information on positive and negative products calculated by MFCA is added. This way, the carbon emissions and cost information of negative products can be shown at the same time, and carbon emission reduction behavior can be encouraged. Here, MFCA is positioned as a tool to promote specific improvement activities in CFP [24].

b. Process-based partially integrated type

The process-based partial integration type is a method that integrates a part of LCA (CFP) based on MFCA. This integration type consists of MFCA and LCA (CFP) CO_2 intensity or LIME integration factor. By integrating a part of MFCA and LCA (CFP), the environmental load information is not only weight but also carbon emissions or social cost, which has the advantage of highlighting the effect of MFCA on environmental conservation (e.g., for example, the effect of LCA (CFP) on the environmental cost of a product). This has the advantage that the environmental impact of MFCA can be understood not only in terms of weight but also in terms of carbon emissions or social costs (e.g., [24]). This is expected to promote the introduction of MFCA to companies and help them to reduce material losses and at the same time, reduce the carbon burden of material losses.

4.2 Analysis based on the CMA framework

Of the 21 studies collected, those that did not address specific integration models were excluded9, and the remaining 16 studies were categorized according to the CMA framework [10]. The results are shown in Table 3. The table shows that 14 studies focus on the provision of short-term, past-oriented information on carbon emissions, and only two studies consider the provision of short-term, future-oriented information. The two papers examining future-oriented information [28, 29] were able to go beyond past-oriented information and provide future-oriented information by linking a model that links parts of MFCA and LCA to a budget management system. As shown in Table 3, the provision of long-term information was not considered in the collected previous studies.

Table 3. Previous studies and CMA framework

		Physical and Monetary Unit Carbon Accounting	
		Short-Term	Long-Term
Past-oriented	Periodically generated information	① Bresciani et al. (2023), Schmidt (2015), Pratt, Lenaghan, & Mitchard (2016), Doorasamy (2016)	⑤ None
	Information for special purposes	② Bresciani et al. (2023), Dekamin & Barmaki (2019), Ho et al. (2021), Sulong, Sulaiman, & Norhayati (2015), Guenther et al. (2017), Seifbarghy, Hamidi, & Chattinnawat (2022), Fakoya, & Imuezerua (2021), Qian, Burritt, & Chen (2015), Christ, & Burritt (2017), Dekamin, Kheiralipour, & Afshar (2022), Zeng, Zhou, & Xiao (2021)	⑥ None
Future-oriented	Periodically generated information	③ Wagner (2015)	⑦ None
	Information for special purposes	④ Nyide (2016)	⑧ None

4.3 Roles and limitations of the three identified integration models

Next, Table 4 shows the results of comparing the three integration types identified in previous studies against the CMA framework.

Table 4. Three integrated types and CMA frameworks

		Quantity and Monetary Unit Carbon Accounting	
		Short-Term	Long-Term
Past-oriented	Periodically generated information	Process-based, partially integrated	⑤ None
	Information for special purposes	Integration, process-based partial integration, product-based partial integration	⑥ None
Future-oriented	Periodically generated information	Integrated (integrated with budget management system)	⑦ None
	Information for special purposes	Integrated (integrated with budget management system)	⑧ None

From the scope of application of the prior literature, the linkage type is characterized by its ability to provide information only for special purposes. Prior studies have shown that the federated type itself can support decision-making for special purposes, such as evaluating the economic and environmental effectiveness of new technology after its introduction (e.g., [30]) or product value chain selection (e.g., [29]. For example, it has been proposed that linking budget systems with MFCA can be expanded to provide regularly generated future-oriented information (e.g., [28, 29]). Thus, it has been pointed out that the linkage type can contribute to the pollution control activities of firms because it collects monetary and physical carbon information for special purposes [26]. However, it is difficult to incentivize carbon reduction in the linkage type because it does not show how the physical carbon emission information calculated by LCA (CFP) is related to the cost information by MFCA.

From the scope of application of the previous literature, it can be said that the product-based partial integration type is characterized mainly by its ability to provide information from a short-term perspective. In addition, prior studies have pointed out that providing the relationship between costs and carbon emissions obtained by this method is effective for long-term decision-making such as green procurement, capital investment, and environmentally conscious product design [24]. However, how to specifically support long-term decision-making using this method has not been examined. Since long-term decision-making requires information from a longer-term perspective, for example, capital budgets, corporate strategies, and consumer preferences, existing integrated models merely provide information from a short-term perspective of costs and carbon emissions, making it difficult to encourage managers to make long-term decisions that take carbon reduction into account. It is difficult to encourage managers to make long-term decisions that take carbon reduction into account. There is also a concern that adding MFCA thinking may focus only on the reduction of negative products and ignore the carbon carried by the material of positive products. In this way, it may impede decision-making, such as procurement of raw materials and product design that emit less carbon.

Based on the scope of application of the previous literature, the process-based partial integration type is the most studied method among the integrated models (12 out of 21 collected are process-based integrated, as shown in Table 2). The method is based on the short-term perspective of finding economic and environmental inefficiencies in the manufacturing process (e.g., [31, 32]) and improving the environmental performance of the entire supply chain (e.g., [33, 34]. In the case that regularly generated information (e.g., [31, 34] oriented toward the short-term perspective of improving environmental performance (e.g., [34, 35]) is needed, information for special purposes such as comparing economic and environmental improvement results before and after improvements in production methods [36, 37] is required (e.g., [38]).

In addition, as explained in Section 2.3, this integrated type can emphasize the environmental conservation effect of MFCA because it can evaluate the carbon reduction effect through the reduction of material losses by integrating it with LCA (CFP). In other words, the greatest advantage of this integrated model is that it can further reduce material losses in a company or supply chain by emphasizing the environmental conservation benefits of MFCA. Therefore, it is necessary to have the same quality of carbon-related quantity information as the management information that MFCA has to enable management decision-making [34]. However, it is pointed out that inventory data information in LCA (CFP) is calculated based on the average value of the input-output table and cannot reflect the individuality of each company, and that there are still many obstacles to overcome before it can be as high as cost information because the number of material item items handled is still small at present [34]. Another issue is how to share information by MFCA among supply chains to develop the integrated model from the manufacturing process to the supply chain [35].

Through the above discussion, the overall issues of the previous studies and each of the integrated types can be summarized as follows.

- The common challenge of the three existing integrated models is that they can only provide short-term and past-oriented information and not long-term information, as shown in Table 3.
- A common challenge of the collaborative model is that it does not provide information on the relationship between the quantity and cost of carbon emissions, which makes it difficult to provide incentives for carbon reduction.
- A common challenge for product-based partial integration is that it is difficult to encourage management to make long-term decisions on green procurement, capital investment, and environmentally conscious product design.
- Another common issue of product-based partial integration is that the use of MFCA tends to focus on the carbon carried by material losses rather than all carbon emissions carried by materials, which may inhibit product development and capital investment considering zero carbon and low carbon emissions. This may inhibit product development and capital investment in consideration of zero carbon and low carbon emissions.
- In the process-based partially integrated model, the quality of information on LCA (CFP) to support internal corporate management decision-making is still lower than that of MFCA [34].
- The process-based partially-integrated model has another issue of how to share the information from MFCA among the supply chain to extend it to the supply chain [35].

4.4 Why the full integration of MFCA and LCA (CFP) could not be identified

In Section 2.3, we categorized the methods of integrating MFCA and LCA (CFP) into three types, i.e., the linkage type, the partial integration type, and the fully integrated type. In the previous study, the linkage type and the partial integration type were identified, but the fully integrated type was not found. In this section, we clarify the reason why the fully integrated type cannot be identified.

As mentioned in Section 2.3, there are two types of fully integrated types: LCA (CFP) based and MFCA-based. The reasons why the LCA (CFP)-based fully integrated type and the MFCA-based integrated type cannot be formed are shown separately below.

The LCA (CFP)-based fully integrated type is said to be difficult to integrate for the following three reasons [39].

- The scope of the application of MFCA is narrower than that of LCA. The scope of the application should be fully integrated into LCA (CFP). However, MFCA can theoretically be extended to the supply chain if information can be shared among the production process and the largest suppliers, but MFCA itself is difficult to extend to the life cycle because it cannot provide costs related to the downstream of the life cycle.
- The MFCA information is used within organizations,

so the information is highly individualized, making comparisons among organizations difficult.

- The difference in the scope of data collection: MFCA only needs to know the weight and amount of purchased materials, while LCA (CFP) requires more detailed information than MFCA because it needs information on the composition of materials. To fully integrate MFCA into LCA (CFP), it is necessary to measure and collect a vast amount of data covering the entire company.

MFCA is valuable in that it divides products into "positive" and "negative," and clearly shows managers opportunities to reduce "negative products" by applying a value to "negative products." However, MFCA is not considered to have much significance in applying to all stages of the CFP life cycle because it is not considered necessary to divide costs into two stages, use and disposal, into positive and negative.

On the other hand, the MFCA-based fully integrated model is said to be difficult to integrate for the following two reasons [24].

- The difference in the measurement targets: The labor costs of factories and depreciation costs of facilities, which are important measurement targets for MFCA, are not included in the scope of LCA (CFP).
- MFCA is based on actual values such as measured values, which are useful information for management decision-making, while some data of LCA (CFP) are estimated values, which are difficult to use for management decision-making.

Therefore, due to the differences in the measurement ranges of the two methods, the technical difficulties of the measurement, and the low significance of integration, there is little need to fully integrate the two methods.

5. CONCLUSION

This paper focuses on the integration of MFCA and LCA (CFP), a CMA method that can incentivize firms to reduce carbon. A literature review was conducted to identify the decision-making situations and limitations that MFCA and LCA (CFP) integration models can support. Twenty-one previous literature were collected and three types of MFCA and LCA (CFP) integration methods were identified: collaborative, product-based partial integration, and process-based partial integration. Next, the collected prior literature was analyzed based on the CMA decision-making framework [10], and the following six issues were identified.

- The common challenge of the three existing integrated models is that they can only provide short-term and past-oriented information and cannot provide long-term information, as shown in Table 3.
- The common issue of the integrated model is that it is difficult to provide incentives for carbon reduction because it does not show the relationship between the physical information of carbon emissions and the cost information.
- The common problem of the product-based partially integrated model is that it is difficult to encourage management to make long-term decisions on green procurement, capital investment, environmentally conscious product design, and so on.
- Another common issue of product-based partial integration is that the use of MFCA tends to focus on the carbon emissions of material losses rather than all the carbon emissions carried by materials, which may impede product development and capital investment with zero or low carbon emissions in mind. This may inhibit product development and capital investment in consideration of zero carbon and low carbon emissions.
- In the process-based partially-integrated model, the quality of LCA (CFP) information to support internal corporate decision-making is still lower than that of MFCA.
- Another issue is how to share the information from MFCA among supply chains to extend the process-based partially integrated model to the supply chain.

In recent years, countries and environmental NGOs have been calling on companies to make significant carbon reductions. Companies need to strategically reduce carbon emissions to avoid risks such as future increases in carbon pricing and downsizing of fossil fuel-related businesses and to create business opportunities by offering new low-carbon products and technologies. Therefore, a strategic management accounting method that can support the implementation of carbon reduction strategies is desired. However, existing integrated models cannot support long-term decision-making at this stage. Therefore, we believe that the integrated model can be linked to strategies and support long-term decision-making related to corporate carbon reduction by linking the integrated model to management control systems. Therefore, it is necessary to study in detail the relationship between the management control system and the integrated model as the next issue.

APPENDIX

Appendix 1: The Paris Agreement is a new agreement to reduce carbon emissions concluded at the 21st Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change (UNFCCC) held in 2015. The Agreement entered into force in November 2016, with a "2°C target" to "keep the global average temperature increase well below 2°C above pre-industrial levels and pursue efforts to limit it to 1.5°C," requiring countries to submit their reduction targets every five years to meet the 2°C target (UNFCCC, 2015). To achieve the 2°C targets, each country is now required to submit its reduction target every five years (UNFCCC, 2015).

Appendix 2: The Climate Group is an international business initiative operated by the Climate Group and CDP, an international environmental NGO, to promote the conversion of all electricity consumed by companies to renewable energy (RE100 website).

Appendix 3: SBTi is a joint initiative of the World Wide Fund for Nature (WWF), CDP, World Resources Institute (WRI), and the UN Global Compact. Based on the IPCC report, the Initiative calls on companies to set long-term GHG reduction targets consistent with scientific findings toward the goal of limiting the increase in global average temperature due to climate change to a maximum of less than 2°C above pre-industrial levels (SBT website).

Appendix 4: Stranded assets: Defined as assets that suffer unexpected or premature write-downs, devaluations, or conversion to liabilities [5].

Appendix 5: Eco-efficiency is a kind of cross-efficiency that links environmental and economic issues and measures the environmental impact added per monetary unit earned. Specifically, eco-efficiency can be defined as minimizing negative outputs while maintaining or improving two economic successes, and outputs are determined based on the amount generated by a particular input level [6].

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REFERENCES

[1] Allan, R.P., Arias, P.A., Berger, S., Canadell, J.G., Cassou, C., Chen, D., Zickfeld, K. (2023). Intergovernmental panel on climate change (IPCC). summary for policymakers. In Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, pp. 3-32. Cambridge University Press. Cambridge University Press, Cambridge, United Kingdom and New York, USA, pp. 3-32. https://doi.org/10.1017/9781009157896.001

[2] Intergovernmental Panel on Climate Change. (2018). Organization. https://www.ipcc.ch/organization/organization.shtml.

[3] UNFCCC. WEF (World Economic Forum). (2021). Global Risk Report, WEF.

[4] Ministry of Environment, Forest and Climate Change (2021). Annual Report.

[5] Caldecott, B., Kruitwagen, L., Dericks, G., Tulloch, D.J., Kok, I., Mitchell, J. (2016). Stranded assets and thermal coal: An analysis of environment-related risk exposure. Stranded Assets Programme, SSEE, University of Oxford. https://doi.org/10.2139/ssrn.2724550

[6] Cordova, C., Zorio-Grima, A., Merello, P. (2021). Contextual and corporate governance effects on carbon accounting and carbon performance in emerging economies. Corporate Governance, 21(3): 536-550. https://doi.org/10.1108/CG-10-2020-0473

[7] Revellino, S. (2020). Accounting for carbon emissions: Simulating absence through experimental sites of material politics. Sustainability Accounting, Management and Policy Journal, 11(3): 613-640. https://doi.org/10.1108/SAMPJ-04-2017-0033

[8] Le Breton, M., Aggeri, F. (2020). The emergence of carbon accounting: How instruments and dispositifs interact in new practice creation. Sustainability Accounting, Management and Policy Journal, 11(3): 505-522. https://doi.org/10.1108/SAMPJ-09-2017-0111

[9] Gunarathne, N., Lee, K.H., Kaluarachchilage, P.K.H. (2023). Tackling the integration challenge between environmental strategy and environmental management accounting. Accounting, Auditing & Accountability Journal, 36(1): 63-95. https://doi.org/10.1108/AAAJ-03-2020-4452

[10] Burritt, R.L., Schaltegger, S., Zvezdov, D. (2011). Carbon management accounting: Explaining practice in leading German companies. Australian Accounting Review, 21(1): 80-98. https://doi.org/10.1111/j.1835-2561.2010.00121.x

[11] Rounaghi, M.M. (2019). Economic analysis of using green accounting and environmental accounting to identify environmental costs and sustainability indicators. International Journal of Ethics and Systems, 35(4): 504-512. https://doi.org/10.1108/IJOES-03-2019-0056

[12] Sari, R.N., Pratadina, A., Anugerah, R., Kamaliah, K., Sanusi, Z.M. (2021). Effect of environmental management accounting practices on organizational performance: Role of process innovation as a mediating variable. Business Process Management Journal, 27(4): 1296-1314. https://doi.org/10.1108/BPMJ-06-2020-0264

[13] Ferdous, M.I., Adams, C.A., Boyce, G. (2019). Institutional drivers of environmental management accounting adoption in public sector water organisations. Accounting, Auditing & Accountability Journal, 32(4): 984-1012. https://doi.org/10.1108/AAAJ-09-2017-3145

[14] Marrone, M., Linnenluecke, M.K., Richardson, G., Smith, T. (2020). Trends in environmental accounting research within and outside of the accounting discipline. Accounting, Auditing & Accountability Journal, 33(8): 2167-2193. https://doi.org/10.1108/AAAJ-03-2020-4457

[15] Adams, C.A., Larrinaga, C. (2019). Progress: Engaging with organisations in pursuit of improved sustainability accounting and performance. Accounting, Auditing & Accountability Journal, 32(8): 2367-2394. https://doi.org/10.1108/AAAJ-03-2018-3399

[16] Jiang, Y., Tang, Q. (2023). Mandatory carbon reporting, voluntary carbon disclosure and ESG performance. Pacific Accounting Review, 35(4): 534-561. https://doi.org/10.1108/PAR-08-2022-0133

[17] Burritt, R.L., Hahn, T., Schaltegger, S. (2002). Towards a comprehensive framework for environmental management accounting-links between business actors and environmental management accounting tools. Australian Accounting Review, 12(27): 39-50. https://doi.org/10.1111/j.1835-2561.2002.tb00202.x

[18] International Organization for Standardization. (2018). Greenhouse gases: Carbon footprint of products: Requirements and guidelines for quantification. International Organization for Standardization.

[19] ISO 14051, I.S.O. (2011). Environmental management-material flow cost accounting-General framework. International Organization for Standardization, Geneva.

[20] Zhang, J., Qian, X., Feng, J. (2020). Review of carbon footprint assessment in textile industry. Ecofeminism and Climate Change, 1(1): 51-56. https://doi.org/10.1108/EFCC-03-2020-0006

[21] Chan, E.S.W. (2021). Why do hotels find reducing their carbon footprint difficult? International Journal of Contemporary Hospitality Management, 33(5): 1646-1667. https://doi.org/10.1108/IJCHM-10-2020-1151

[22] Brunelli, S., Falivena, C., Carlino, C., Venuti, F. (2021). Accountability for climate change: A research synthesis through the lenses of the integrated thinking approach. Meditari Accountancy Research, 29(4): 1005-1038. https://doi.org/10.1108/MEDAR-01-2020-0682

[23] Christ, K.L., Burritt, R. (2017). Material flow cost accounting for food waste in the restaurant industry. British Food Journal, 119(3): 600-612. https://doi.org/10.1108/BFJ-07-2016-0318

[24] O'Dwyer, B., Unerman, J. (2020). Shifting the focus of sustainability accounting from impacts to risks and dependencies: Researching the transformative potential of TCFD reporting. Accounting, Auditing & Accountability Journal, 33(5): 1113-1141. https://doi.org/10.1108/AAAJ-02-2020-4445

[25] Walz, M., Guenther, E. (2021). What effects does material flow cost accounting have for companies? Evidence from a case studies analysis. Journal of Industrial Ecololgy, 25: 593-613. https://doi.org/10.1111/jiec.13064

[26] Bui, B., de Villiers, C. (2017). Business strategies and management accounting in response to climate change risk exposure and regulatory uncertainty. The British Accounting Review, 49(1): 4-24. https://doi.org/10.1016/j.bar.2016.10.006

[27] Bierer, A., Götze, U., Meynerts, L., Sygulla, R. (2015). Integrating life cycle costing and life cycle assessment using extended material flow cost accounting. Journal of Cleaner Production, 108(B): 1289-1301. https://doi.org/10.1016/j.jclepro.2014.08.036

[28] Wagner, B. (2015). A report on the origins of material flow cost accounting (MFCA) research activities. Journal of Cleaner Production, 108: 1255-1261. https://doi.org/10.1016/j.jclepro.2015.10.020

[29] Nyide, C. (2016). Material flow cost accounting as a tool for improved resource efficiency in the hotel sector: A case of emerging market. Risk Governance & Control: Financial Markets & Institutions, 6(4-3): 428-435. https://doi.org/10.22495/rcgv6i4c3art8

[30] Zeng, H., Zhou, Z., Xiao, X. (2021). MFCA extension from a life cycle perspective: Methodical refinements and use case. Resources Policy, 74: 101507. https://doi.org/10.1016/j.resourpol.2019.101507

[31] Bresciani, S., Rehman, S.U., Giovando, G., Alam, G.M. (2023). The role of environmental management accounting and environmental knowledge management practices influence on environmental performance: Mediated-moderated model. Journal of Knowledge Management, 27(4): 896-918. https://doi.org/10.1108/JKM-12-2021-0953

[32] Dekamin, M., Kheiralipour, K., Afshar, R.K. (2022). Energy, economic, and environmental assessment of coriander seed production using material flow cost accounting and life cycle assessment. Environmental Science and Pollution Research, 29: 83469-83482. https://doi.org/10.1007/s11356-022-21585-0

[33] Fakoya, M.B., Imuezerua, E.O. (2021). Improving water pricing decisions through material flow cost accounting model: A case study of the politsi water treatment scheme in South Africa. Environment, Development and Sustainability, 23: 2243-2260. https://doi.org/10.1007/s10668-020-00672-7

[34] Sabir, R.A., Al-Zebari, H.H.H. (2022). The impact of the application of material flow cost accounting (MFCA) technology on reducing costs and rationalizing administrative decisions. Academic Journal of Nawroz University, 11(4): 266-283. https://doi.org/10.25007/ajnu.v11n4a1461

[35] Flayyih, H.H., Chichan, H.F., Hamdan, N.F. (2021). The impact of accounting for material flow costs in reducing costs: Exploratory study. Social Science and Humanities Journal, 5(5): 2204-2217.

[36] Dekamin, M., Barmaki, M. (2019). Implementation of material flow cost accounting (MFCA) in soybean production. Journal of Cleaner Production, 210: 459-465. https://doi.org/10.1016/j.jclepro.2018.11.057

[37] Ho, J.Y., Ng, D.K.S., Wan, Y.K., Andiappan, V. (2021). Synthesis of wastewater treatment plant based on minimal waste generation cost: A material flow cost accounting (MFCA) approach. Process Safety and Environmental Protection, 148: 559-578. https://doi.org/10.1016/j.psep.2020.10.013

[38] Sulong, F., Sulaiman, M., Norhayati, M.A. (2015). Material flow cost accounting (MFCA) enablers and barriers: The case of a Malaysian small and medium-sized enterprise (SME). Journal of Cleaner Production, 108: 1365-1374. https://doi.org/10.1016/j.jclepro.2014.08.038

[39] Qian, W., Burritt, R., Chen, J. (2015). The potential for environmental management accounting development in China. Journal of Accounting & Organizational Change, 11(3): 406-428. https://doi.org/10.1108/JAOC-11-2013-0092