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Review

Relationship between Green Design and Material Flow Cost Accounting in the Context of Effective Resource Utilization

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Abstract: The consumption of fossil fuels has been gradually exhausting resources and deteriorating the environment on a global scale. There are two ways to resolve these problems: The application of green energy and new materials; and the development of energy efficiency techniques such as green design and material flow cost accounting. Material flow cost accounting does not create new sources of energy, but its implementation can encourage the effective use of resources or reduce the consumption of resources, and hence reduce the impact on the environment. The International Organization for Standardization has enacted material flow cost accounting as an international standard, and this will have a profound impact on multinational firms. This paper examines material flow cost accounting in the context of grounded theory, and conducts a case study on the companies which have implemented material flow cost accounting. The purpose of this research is to identify the relationship between material flow cost accounting and green design, and to provide a reference for the production design of the enterprise. After analysis, material flow cost accounting can generate detailed waste data, and provide a green design reference in actual energy conservation. These two outcomes complement each other, and will support achievement of the goal of mutual financial and environmental protection.

Keywords: ISO-14051; material flow cost accounting; green design; green accounting

1. Introduction

The deterioration of the global environment has led to the rise of corporate social responsibility. The increasingly forceful demands, made by much of society, that companies be responsible for their unethical practices [1]. Various improvement tools have come out. Schaltegger pointed out that the development of sustainability accounting and reporting should be orientated more towards improving management decision making [2]. One of the tools to improve management decisions is material flow cost accounting (MFCA). MFCA and green design share the same goal of environmental protection. They are both aimed towards the effective utilization of resources. For this reason, this paper sets out to explore the relationship between MFCA and green design. Job order costing and processing costing systems are the methods utilized in cost accounting to calculate the final costs of products, by adding up expenses throughout different divisions. Both methods accumulate or distribute the costs associated with defects, spoilage, and waste to the finished goods or work in process, or simply recognize such costs as expenses or losses during the period [3]. Neither method pays attention to the efficiency of resource utilization. This is why material flow cost accounting advocates the reduction of waste and resource consumption. The ISO-14051 standard declares that waste materials are the result of material losses and resource wastefulness. This paper reviews all the relevant literature from different countries, before and after the release of the ISO-14051, and finds that all studies support material flow cost accounting. These studies include Kokubu et al. [4] from Japan, Schmidt, and Nakajima [5] from Germany and Japan, and Christ and Burritt [6] from Australia. The MFCA Manual [7], published by the Asian Productivity Organization, the MFCA Booklet [8], published by the National Productivity Council of India, and even the Thai government [9] have all enlisted the ISO-14051 as a national standard. It is the general consensus that the implementation of material flow cost accounting will reduce the consumption of materials and energy, and the impact on the environment. It will also benefit the economy and company financial outcomes, as intended by the ISO-14051 standard, which has a focus on the balance between the input of materials or energy and the output. It is required that the materials used for production should be equal to the consumption of the products, leftovers, and waste materials. All the consumption and leftovers in each stage of production and processing are recorded in detail. The calculation of the manpower and disposal costs associated with waste disposal is made, in order to provide information to design or manufacturing personnel for future improvements. Despite the claimed functions of MFCA, this paper argues that calculation requirements alone cannot reduce resource consumption or improve resource utilization efficiency throughout production procedures. It is necessary to incorporate other methods or techniques (such as green design), and leverage the information provided by material flow cost accounting, so as to devise measures to reduce waste and spoilage. Some scholars have pointed out that the methodology is being extended, refined, and elaborated, and increasingly applied in combination with various other tools and concepts [10]. Therefore, this paper seeks to explore the context of MFCA by referring to the articles of ISO-14051, a comprehensive international standard of MFCA. The purpose of this is to examine whether the essence of this standard contains the expectations for green design, and the intention to introduce other techniques or methods to achieve energy efficiency. For the companies that have implemented MFCA to improve energy efficiency, this paper intends to explore what approaches they have adopted, and whether green design is included. Case studies are conducted on selected companies to analyze whether their improvement measures are related to green design techniques and methods. If both answers are yes, as expected by this paper, it can be concluded that MFCA and green design are complementary in promoting the effective utilization of resources.

2. Development of MFCA

Material flow cost accounting was first developed in the middle of the 1990s by Professor Bernd Wagner from the Institut fuer Management und Umwelt in Augsburg, Germany. It was introduced to Japan in 2000, and has been widely adopted in Japan since then. In 2008, the Japanese Industrial Standards Committee formulated a set of standards regarding material flow cost accounting for review by the International Standards Organization (ISO). The proposal was approved by the ISO Technical Committee 207, and Working Group 8 was established under the guidance of the ISO Technical Committee 207 to formulate the ISO-14051 standards. A working draft was released in March 2009, and the ISO-14051 was formally published as part of the environmental management series in November 2011 [11]. Before becoming an international standard, material flow cost accounting was known as material flow analysis, as part of green accounting in the US and Europe. The United Nations Division for Sustainable Development [12] considers green accounting as an environmental management tool to confirm and collect data regarding natural resources, material flow, and environmental improvement, as well as an analytical measurement to link environmental costs and financial information for the reference of company management and environmental decisions. The ultimate goal is to connect the management of environment planning and economic policies at the corporate level to achieve sustainability. The International Federation of Accountants [13] issued the guidelines for environmental management accounting in 2005, by defining it as the confirmation, collection, analysis, and utilization of physical information and monetary information so as to facilitate internal decisions. Physical information measures the consumption and movement of energy, water, and raw materials, and the changes and disposal of waste. Monetary information is the currency expression of quantified approximations of the costs and benefits, tangible and intangible, in terms of environmental improvement and resource conservation. Meanwhile, the United Nations Division for Sustainable Development refers to material flow analysis as the analysis of natural resources and physical flows. The International Federation of Accountants defines material flow analysis as the analysis of physical information. Both terms mean the analysis of material flows, as it involves the valuation and analysis of the input and output of materials throughout the production workflows, and then the comparison of costs, calculated and expressed in monetary amounts. The analysis of material flows, developed outside green accounting in Japan, added the term "costs". The result was "material flow cost accounting". Based on the articles of the ISO-14051 [14], this paper defines material flow cost accounting as the material balancing in accounting for the inputs of all the energy, water, and raw materials, and the outputs of products and waste. The International Standards Organization believes that material balancing—that is, inputs equating to outputs—ensures that all the inputs of raw materials and energy, and all the outputs of products and waste throughout the production activities, are tracked and accounted for. It is assumed that all the inputs are converted into outputs (i.e., products and waste). All the costs and expenses associated with energy and raw materials are recorded, tracked, and managed over a period of time. Material flow cost accounting is about the collation of quantitative data concerning the acquisition, transportation, internal allocation, utilization, and inventory of raw materials, the storage and shipping of finished goods, and the recycling, reusing, or disposal of waste. With a history of more than three decades, the concepts and techniques of green design can be considered relatively mature, and hence this paper does not intend to elaborate on them. That said, this paper has highlighted its philosophy in another article, as follows: (1) maximize output with a given level of input, (2) avoid pollution, (3) pursue clean production, (4) reduce impact, (5) improve environmental performance, and (6) equate input to output [15].

3. Material and Methods

3.1. Method

MFCA presumes that material flow cost accounting reduces resource consumption and environmental impact. Whilst this is a great idea, whether it is true is another issue. Its development has so far been a phenomenon, and no definite conclusions have been drawn. This paper seeks to ground the research in each element of the phenomenon, and the development of material flow cost accounting. The ISO-14051 Standard, Environmental Management—Material Flow Cost Accounting—General Framework, is a set of standardized requirements developed to track and record the costs associated with leftovers, waste, and excess materials by applying the techniques of cost accounting. Excess materials refer to the redundant elements which occur when the input materials are greater than the sum of the products, leftovers, and waste. Improvements should start from waste and excess materials. This paper grounds its research in the ISO-14051 standard, as it is becoming the guideline for material flow cost accounting, and energy efficiency and environmental protection for corporates. The purpose is to identify whether the rules contain the implicit expectations for green design in the design or manufacturing process, to reduce resource waste. To support the interpretation of ISO-14051, this paper conducts case studies on forty companies that have implemented MFCA, to understand whether green design is in use to enhance the effective utilization of resources.

Grounded theory emphasizes the development of theories by anchoring with data. It considers the induction of propositions to explain and interpret certain phenomena. Theories and prejudices cannot be developed upon any new discovery. Rather, concepts and scopes are gradually synthesized through research and analysis. The induction of theories starts from the coding process [16]. Generally speaking, grounded theory is considered the most scientific approach to qualitative studies. It is one of the more highly valued research methods social studies. Grounded theory collates data in a systematic manner, and uses the scientific approach of inferences to generalize and analyze specific circumstances. It is hoped that this bottom-up approach can establish new theories that reflect social phenomena.

Put differently, grounded theory is not about proving a pre-developed theory. Rather, it is the synthesis of concepts and theories about a subject that is yet to be extensively researched [17]. In a nut shell, grounded theory is a quantitative method that systematically collates data and then consolidates and analyzes such data, with layers of coding from complexity to simplicity. This research methodology aims to uncover or reflect social phenomena.

Grounded theory deciphers data into three levels: open coding, axial coding, and selective coding. Open coding contextualizes the transcriptions of the raw data, and extracts the texts in each paragraph in order to form a consistent concept of the same nature or dimensions within a specific scope. Axial coding is the analysis of the open codes, by integrating the factors with the same causality and background. This allows the generalization of complex phenomena into concise and simple concepts. Selective coding retains the factors relevant to the research by predetermining a set of criteria. This process aims to induct and generalize a set of principles regarding the relationships previously questioned and intended for exploration, and then develop the central notions closer to reality. The use of selective codes to interpret events, facts, and social phenomena allows researchers to clarify their questions, and identify the relationships in relation to the subject matter.

3.2. Research Process

This paper uses open codes to contextualize all the relevant texts throughout the ISO-14051 articles as raw materials. This process treats each article as an analytical unit, and extracts the texts with specific meanings. If an article is short, it is completely selected in order to avoid distortions. The first column in List A1 (Appendix A) summarizes the selection results. The second step is to use axial coding on the results of the open coding in order to distill the underlying concepts, requirements, or action items. The second column in List A1 presents the findings of axial coding. Up to this point, all coding is grounded in the ISO-14051 paragraphs, without any personal interpretation by the researchers. The third stage is the application of selective coding, by deciding on the elements relevant to research topics. The issues associated with green design are incorporated by this paper in order to explore whether green design and the effective utilization of resources intended by material flow cost accounting are related, and identify the timing and occasion for green design. The third column in List A1 shows the results of selective coding. The coding process was completed via multiple meetings consisting of the author, two researchers, and the two thesis advisors.

The ground process is long and tedious, as it requires word-by-word reading and translation in order to understand the meanings and categorize the texts in terms of the actions and accountability required. This paper only provides a few examples. Please refer to List A1 (Appendix A) for the grounding results of all the ISO-14051 paragraphs.

Example 1. *The first paragraph listed in the first example in List A1. ISO-14051 texts: This International Standard provides a general framework for material flow cost accounting (MFCA). Under MFCA, the flows and stocks of materials within an organization are traced and quantified in physical units (e.g., mass, volume) and the costs associated with those material flows are also evaluated. The resulting information can act as a motivator for organizations and managers "to seek opportunities to simultaneously generate financial benefits and reduce adverse environmental impacts." MFCA is applicable to any organization that uses materials and energy, regardless of their products, services, size, structure, location, and existing management and accounting systems.*

This paragraph deals with the quantification of materials and the estimates of expenses incurred. It is applicable to any organization. This paper concludes that the core concept of this paragraph is to apply the techniques so that companies of any types can achieve both financial benefits and environmental protection. After going through the whole paragraph, this paper determines that the following wording can best represent the central idea, as it reiterates the reduction of the environmental impact in a way that is relevant to the responsibility of green design: "To seek opportunities to simultaneously generate financial benefits and reduce adverse environmental impacts." The above wording is extracted into open codes, as these texts are representative and reflective of the raw materials, and relevant to the research topics. The second step is axial coding—the identification of the key elements from the results of open coding. This stage allows various interpretations. For instance, the purpose of the ISO-14051 is to look for opportunities to improve efficiency, and this is consistent with the responsibility of green design. As the paragraph concerned is a statement for expectations, it should be treated as the mission statement of the ISO-14051 standard. This paper interprets this as a "win–win policy", as material flow cost accounting attempts to seek environmental protection and economic growth at the same time. The final stage is selective coding by grouping the results of axial coding into specific factors according to attributes. As this paper intends to analyze the overall attributes of the ISO-14051 standard, given its importance to material flow cost accounting and relevance to environmental management, the attributes identified are accounting elements, regulatory requirements, central concepts, and green design. The central concept is the appeal for the win–win. This paper decides to classify the requirement in this paragraph as the mission statement of the ISO-14051 standard.

Example 2. *Example No. 18 in List A1 is Article 3.15, ISO-14051 texts: "Material flow cost accounting: tool for quantifying the flows and stocks of materials in processes or production lines in both physical and monetary units", the definition of material flow cost accounting by the ISO-14051 standard. The wording is very specific and concise. To avoid misinterpretation as a result of missing texts, this paper uses open coding to contextualize the whole paragraph. The next step is to identify the central concept for axial coding, and this paper determines it is to be the definition of material flow cost accounting. The final step is selective coding. This paper determines this paragraph deals with the system and nothing else and, hence, classifies it into system requirements.*

Example 3. *Example No. 55 in List A1 is about Article 6.9. The original texts are very long and come with tables to illustrate calculations. It is necessary to read through the complex texts in order to distill its central concept. The calculations and explanations accompanied with the tables in the article detail the process of costing. " ... review and interpretation of the summarized data will allow the organization to identify quantity central with material losses ... be analyzed in more detail to identify the root causes of the material losses and the associated factors that incur the costs." The above wording deals with the selection for the tabulated data for further analysis so as to identify the cause for material losses. This is determined to be the central concept of the whole paragraph and, hence, extracted into open coding. The idea is to identify the reasons for a lack of efficiency in material consumption with the information revealed. This paper believes that green design should come to the fore in order to achieve improvements, once the reasons for inefficiency are identified. Hence, this paper classifies these texts with selective coding into "the factors that require the introduction of green design" in the final stage of attribute categorization.*

The coded results and the core concepts of the ISO-14051 standard are summarized in List A1. The ISO-14051 standard is an accounting system of cost management, aiming to provide information and introduce green design. Its purpose is to effectively utilize resources and reduce resource wastes and environmental pollutions. This paper goes through all 57 articles of the ISO-14051 standard, and derives the following statistics regarding the relevant attributes:

(1) Mission statement: Three articles

The purpose of the standard, as an element of environmental management, is to identify the opportunities to achieve both financial benefits and environmental protection in the process of product manufacturing.

(2) Core concepts: Four articles

This is the underlying concept throughout the standards; that is, the improvement of manufacturing procedures can achieve energy efficiency and environmental protection. It is necessary to value and balance the inputs and outputs throughout the workflows by tracking the destination of materials. Material loss resulting from the manufacturing process should not be added onto products.

(3) Calculation methodology: Three articles

This is a mechanism for cost estimation and quantification, and is called the "quantity center" in the standards. Its purpose is to identify waste in different forms.

(4) Unit consistency: Five articles

It is reiterated throughout the standard that the unit and the currency used to quantify the materials and energy, and their changes throughout the manufacturing process, should be consistent.

(5) System requirements: 16 articles

Five articles only provide titles. Others define the framework and operational mechanisms of material flow cost accounting.

(6) Costing requirements: 13 articles

These articles define costs and sets out the procedures for cost allocations and categorization.

(7) Cost estimates: Six articles

These articles articulate the methods of calculating cumulative product costs by tallying the quantity of leftovers or inventory, wasted materials, management, and disposal costs.

(8) Green design: Seven articles

Material flow cost accounting aims to inform stakeholders that the recycling of materials indicates a lack of efficiency in production. It is necessary to identify the reasons for inefficient use of materials. Material flow cost accounting provides the relevant information and analytical techniques to pinpoint the cause for losses. One of these seven articles mentions expertise, mostly about green design knowledge and competences.

3.3. Results

Whether the resource waste discovered by MFCA can be improved by green design is confirmed by the implementation results released by the Ministry of Economy, Trade and Industry (METI), Japan [18], based on the achievements in energy efficiency obtained by 32 companies, which have implemented material flow cost accounting. The METI report discusses green design throughout. As summarized in Table 1, the 32 companies covered include 23 in manufacturing, five in non-manufacturing, and four chain stores with suppliers in the upper stream and manufacturers in the downstream. Technically speaking, the chain stores in the example can be classified as manufacturers. In other words, a total of 27 companies out of the 32 companies are manufacturers (only the companies numbered 24 to 28 are not in manufacturing). In fact, the ISO-14051 standard also includes five case studies from Japan, Czech, Vietnam, Germany, and the Philippines. These companies, added to Table 1 and numbered from 33 to 37, are also all in manufacturing. As the company numbered 33 and the company numbered 7 are the same Japanese company, a total of 31 companies are summarized for the METI report. The concentration of the case studies in manufacturing indicates that material flow cost accounting is more appropriate for manufacturing.

Table 1. Measures to reduce losses in the framework of material flow cost accounting.

Name of Company	Sector	Cause	Improvement
1. NITTO DENKO CORPORATION	Chemicals	Water of materials	Purchase of better equipment
2. SEKISUI Chemical Co., Ltd.	Chemicals	Low productivity and high percentage of defects	Productivity improvement and cost reduction
3. SUMIRON Co., Ltd.	Chemicals	High percentages of waste materials	Manufacturing process improvement to reduce material loss
4. TOYO INK MFG. Co., Ltd.	Chemicals	Heavy material losses	Equipment upgrade to improve processing speed
5. Sumitomo Chemical Co., Ltd.	Chemicals	Heavy material losses	Production workflow improvement to reduce material consumption
6. Mitsubishi Tanabe Pharma Corporation	Pharmaceutical	High percentage of wastes and cost of management	Change of waste processing methods and reuse of recycled materials
7. Canon Inc.	Electric Appliances	Heavy consumption of materials	Change of processing and manufacturing methods to reduce material consumption
8. Nagahama Canon Inc.	Electric Appliances	High percentage of wastes	Employee training on the reduction of losses and wastes
9. OMRON Corporation	Electric Appliances	High consumption of materials	Re-molding and equipment redesign to accelerate assembly speeds and reduce material costs
10. TS Corporation	Electric Appliances	Low yields	Improvement of production procedures to produce high-value-added products
11. Press Manufacturer A	Electric Appliances	High percentage of wastes	Change of product sizes and manufacturing procedures
12. Katagiri Seisakusho Co., Ltd.	Transportation equipment	High consumption of materials	Improvement of processing techniques and productivity to reduce material costs
13. GUNMA GOHKIN Co., Ltd.	Transportation equipment	High consumption of energy	New equipment and energy conservation measures to reduce energy waste
14. Mitsuya Co., Ltd.	Metal Products	High consumption of indirect materials during processing	Use of alternative materials and change of manufacturing processes to reduce the consumption of water and materials
15. KOSEI Aluminum Co., Ltd.	Metal Products	High percentage of materials that require recycling	Improvement of manufacturing technologies to reduce the requirement for material recycling
16. MIWA LOCK Co., Ltd.	Metal Products	High consumption of materials	Re-molding to reduce material consumption
17. NIPPON FILCON Co., Ltd.	Metal Products	High consumption of materials	Improvement of procedural control to avoid material consumption whilst the machine is idling or out of order
18. Shimizu Printing Inc.	Pulp and Paper	High consumption of materials and manpower	Adjustment of printing procedures to save ink and manpower, based on the suggestion from onsite workers
19. THE REBIRTH Co., Ltd.	Pulp and Paper	Heavy consumption of materials and energy	Improvement of production procedures and the reused of recycled leftovers to reduce the consumption of materials and energy
20. GUNZE Limited	Textiles and Apparels	High defect rates	Redesign and new materials to increase yields
21. Kohshin Rubber Co., Ltd.	Rubber Products	Too much leftover material	Material reuse during the manufacturing process to reduce material waste
22. Shinryo Co., Ltd.	Foods	Defects due to human errors	Operational improvement to increase productivity, materials recycling, and nightshift reduction
23. KODAI SANGYO Co., Ltd.	Other Products	High defect rates	Resetting of procurement standards to reduce defects
24. JFE group	Construction	Decisions over sub-contracting	Evaluations of different engineering techniques by using the information provided by material flow cost accounting
25. GUNZE Limited	Textiles and Apparels	Low product turnovers and high returns	Strategies developed on the basis of material flow cost accounting to reduce losses in the process
26. OHMI BUSSAN, Inc.	Other Services	Inventory and warehousing expenses	Inventory reduction and productivity improvement by using material flow cost accounting as a management tool

Table 1. *Cont.*

Name of Company	Sector	Cause	Improvement
27. Sanden Corporation	Machinery	Equipment deployment costs too high, due to a large number of service outlets	Deployment of shareable equipment for repeated use according to the calculation with material flow cost accounting
28. Convenience store A	Retail Trade	Too much expired food	Precise ordering to reduce waste food and carbon emissions based on the analysis of material flow cost accounting
29. Sanden Corporation SC team	Machinery	Energy and system costs too high	Redesign the production process to reduce material waste, energy consumption, and system costs
30. Panasonic Ecology Systems Co., Ltd. SC team	Electric Appliances Chemicals	Too much waste material	Analysis of the whole supply chain to balance the outputs from upper stream to the inputs for downstream
31. OMRON RELAY and DEVICES Corporation SC team	Electric Appliances Metal Products	High consumption of materials and energy	Optimization of the supply chain by focusing on communication, cost reduction, and technological improvement to reduce environmental effects
32. Ohu Wood Works Co., Ltd. SC team	Metal Products	High material consumption and low yields	Formulating of shared requirements to standardize material requirements, reduce material consumption, and enhance yields
33. The same with 7	Electric Appliances	High consumption of materials	Change of processing procedures to reduce material consumption
34. A small company in the Czech	Manufacturing Factory	Too much waste materials and too high disposal expenses	Improvement of material utilization efficiency by using the analysis of material flow cost accounting as a tool
35. A Vietnamese coffee manufacturing factory	Agricultural Manufacturing	Overuse of fertilizers and materials	Advocate for green coffee beans by initiating training programs to reduce material consumption and environmental impacts
36. A German pharmaceutical company	Pharmaceutical Industry	High consumption of materials and energy	Complete and systematic reporting of materials to reduce spoilage and attrition
37. A peanut manufacturer, Philippines	Snack Producer	Waste of manpower and materials	Establishment of an incentive system and training programs and improvement of production equipment

Source: Compiled by this study.

4. Analysis and Discussion

This paper derives the following percentages (Figure 1) based on the statistics shown in List A1 (Appendix A).

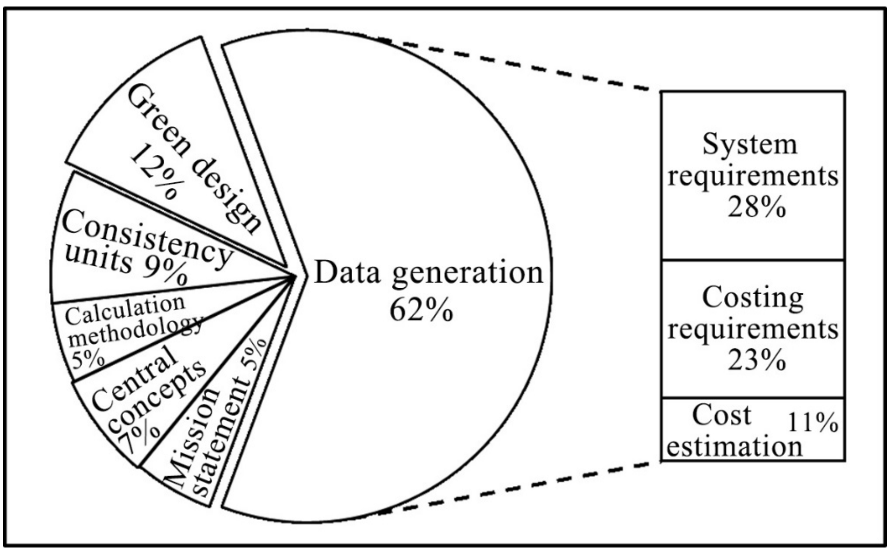

Figure 1. Percentage of ISO-14051 attributes.

(1) Data generation:

Most of the relevant articles outline the methods for the estimation and calculation of the change in materials throughout the production process. A total of 35 articles deal with system requirements, costing requirements, and cost estimates; that is, 62% of the articles are about data generation.

(2) Waste confirmation:

The greatest function of this standard is to pinpoint where, the volume, and the amount of waste. About 34% of the articles on data generation are on the costing rule and cost calculation, to track the usage cost for materials or energy. Any costs not able to be categorized, or the gap between final inputs and output, are defined as waste. The idea is to spot where the waste is in a timely manner.

(3) Mentioning of green design:

The core element, objectives, and green design of waste improvements emphasize the betterment of manufacturing processes for environmental protection and energy efficiency. How the improvements should be made is up to stakeholders—the green design personnel or engineering staff. The purpose of this standard can only be achieved with hands-on improvements by engineers. This accounts for 24% of the total.

(4) Other requirements:

Other requirements refer to the consistency in units for cost calculations, and the definition of calculation mechanisms. This is less relevant to this paper. Eight articles consider this, or 14% of the total.

In sum, there are no straightforward rules on energy efficiency technology in ISO-14051. Whilst the information provided by MFCA is a sufficient basis for improvement, support from engineering and technical knowhow are required to achieve energy efficiency and environmental protection. This is evidenced by 24% of the articles being dedicated to core elements, objectives, and green design, and the pursuit of manufacturing process improvement to achieve environmental protection and energy efficiency. Studies have shown that after obtaining information, it should be administered to plant personnel for hotspot improvements [19]. Same as the analysis of this study. Below is an analysis of the information presented in Table 1. The causes for waste shown in Table 1 are the analytical findings on the basis of material flow cost accounting. The majority of waste is related to materials and energy, in addition to manpower inefficiency, defects, leftovers, and inventory. These are all calculations made with cost accounting techniques. The quantity in central, according to the physical quantities of opening inputs and closing inventories. Whilst the information is provided with material flow cost accounting, the improvement relates to green design techniques and methods. The National Productivity Council, India (2015), in its manual to introduce material flow cost accounting, also uses four manufacturers as examples and green design as the solutions. The report indicates that Japan Productivity sent experts to India to assist with the promotion of material flow cost accounting from June 2012 to March 2014. Four companies were involved in the process: Sainest Tubes Pvt. Ltd. (a manufacturer of carbon steel seamless pipes, Gandhinagar, India), Bhagwati Spherocast (a manufacturer of high duty grey iron and ductile iron castings, Ahmedabad, India), Somany Ceramics (Kadi, India), and Baroda Moulds and Dies (Waghodia, India). The report released by the National Productivity Council describes the issues identified by material flow cost accounting that require improvement. These include material and energy waste, defects, and low productivity. All the details on energy efficiency and material values are available on the official website of the National Productivity Council, India. This paper focuses on the introduction of green energy, in the pursuit of tidiness, cleanness, and precision, to improve productivity with green design, and by upgrading equipment and training employees. The following is a list of the green design techniques and methods from the above literature:

(1) Equipment upgrade: New equipment, re-molding, and equipment redesign;
(2) Design changes: Redesign of products, production flows, and manufacturing methods;
(3) Competence improvement: Employee training in equipment operations so as to reduce waste;
(4) Recycling and reuse: Reuse of waste and recycled leftovers;
(5) Material replacements: Use of alternative materials and development of new materials to reduce energy consumption;
(6) Standard resetting: Renewal of the standards for procurements.

The summary suggests that the 31 companies in the case study, and the four manufacturers in India that have implemented MFCA to resolve waste problems, have all adopted green design techniques and methods. Based on the above findings, this paper believes that both the information provided by material flow cost accounting and the introduction of green design are required to facilitate the effective utilization of corporate resources. This will be a daunting challenge for engineering personnel, because the reduction of waste ultimately depends on the performance of onsite engineers. The data collated via material flow cost accounting and the assessment of such data during the manufacturing process can shed light on the causes of resource waste. It will then be necessary to apply green design and technology to maximize outputs with a given level of inputs. With effective use of resources and reduction of the environmental impact, it will be possible to create a win-win for economic growth and environmental protection.

5. Conclusions

The analysis indicates that 62% of the articles in ISO-14051 are about data generation. It can be hence inferred that MFCA focuses on cost calculations and records. The requirements for improvement technologies or methods are yet to be formulated. This is consistent with the concern raised by this paper: MFCA should be combined with other knowledge and skillsets to achieve materials or energy savings. This paper concludes that the general approach to achieve energy efficiency and environmental protection is to combine green design with material flow cost accounting.

(1) Data generation by material flow cost accounting:

Process costing and job costing in cost accounting calculate the cumulative expenses through different divisions, and derive the final cost for products. However, they ignore the balancing of inputs and outputs of materials or energy. On the contrary, MFCA emphasizes that inputs should equate to outputs. Namely, the materials used for production should equate to usage plus leftover materials, waste materials, and wasted materials. Waste materials and wasted materials are considered a loss of materials, and hence a waste of resources. It is; therefore, necessary to document, in detail, the usage and leftovers for each stage, and estimate the required costs for labor, materials, and energy associated with waste. This information is provided to design or manufacturing personnel as the basis for improvement, so that production staff will seek to reduce leftovers and waste. This is the largest contribution of MCFA to the effective use of resources.

(2) Engineering and technical support required for energy efficiency:

The overall concept and the actual implementation of MFCA capture the tracking of materials and energy used by all production activities. The attention to detail is such that it detects the small variance between inputs and outputs, and ultimately identifies where the waste occurs. Strictly speaking, this is to generate information for internal management. Therefore, it is still necessary to combine domain knowledge and competences, such as technology updates, equipment replacement, and energy efficient material development, to reduce or avoid waste. This ensures environmental protection via energy/material efficiency.

(3) Complementary to green design:

According to Table 1, all the improvement measures start with the calculation of the material costs and subsequent waste on the production lines. This is followed with creative ideas, such as the use of energy efficient materials to reduce waste and lower disposal costs. Other solutions include the redesign of the products and manufacturing processes to avoid waste. The contribution of material flow cost accounting is the information it provides, by evaluating and converting resource loss into monetary values. Engineers then refer to the data collected by material flow cost accounting and devise measures to identify the hidden waste of resources, and apply green design expertise and competences to seek improvement. The creation of a win–win situation for economic growth and environmental protection requires the maximization of outputs with a given level of resources, the reduction of waste and energy consumption, and the switch from waste processing to pollution prevention. In sum, product design should be environmentally friendly from the outset.

(4) For future research:

This study is a preliminary discussion of MFCA and green design. It was found that the two have complementary relationships in effective resource utilization, but no detailed cost–benefit analysis has been revealed. It is harder to convince companies to use green design to improve the material waste found by MFCA. Future research should be directed toward cost analysis of the green design intervention before and after improvement. It is possible to establish actual relevant data for both in increasing the effective use of resources.

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Appendix A

Table A1. Grounded coding on ISO-14051 material flow cost accounting.

No	Open Coding	Axial Coding	Selective Coding
1	1. Scope . . . to seek opportunities to simultaneously generate financial benefits and reduce adverse environmental impacts. Material flow cost accounting (MFCA) can be extended to other organizations in the supply chain, . . . MFCA, one of the major tools of EMA, also focuses on information for internal decision-making, ... information on techniques are outside the scope of this International Standard.	Win–win, complete mobilization, cost data presented, no mention of improvement methods	Mission statement (as well as responsibility of green design)
2	2. Normative references ISO 14050, environmental management is referenced documents . . .	This standard is part of environmental management	Mission statement
3	3. Terms and definitions . . . the terms and definitions given in ISO 14050 and the following apply	Definition of different costs	System requirements
4	3.1. Cost Monetary value of resources consumed . . .	Resource consumption expressed with monetary terms	Consistent units
5	3.2. Cost allocation Indirect attribution of a cost between different objects, . . .	Allocation of indirect costs	Costing requirements
6	3.3. Cost assignment Direct attribution of a cost to a specific object, . . .	Incurrence of direct costs	Costing requirements

Table A1. *Cont.*

No	Open Coding	Axial Coding	Selective Coding
7	3.4. Energy cost . . . electricity, fuels, steam, heat, compressed air, and other like media.	Itemization of energy cost	System requirements
8	3.5. Energy loss All energy use, . . . into intended products.	Allocation of energy loss by product	Costing requirements
9	3.6. Energy use Manner or kind of application of energy . . .	Examples of different types of energy	System requirements
10	3.7. Environmental management accounting -physical information on the use, . . . -monetary information on environment-related costs	Two types of information	System requirements
11	3.8. Input Material or energy flow that enters a quantity center.	Definition of material inputs	System requirements
12	3.9. Inventory Stock of materials, intermediate products, products in process, finished products.	Definition of inventory materials and finished goods	System requirements
13	3.10. Material Substance that enters and/or leaves a quantity center. Materials can be divided into two categories: . . .	Physical materials, direct or indirect	Costing requirements
14	3.11. Material balance Comparison of physical quantities of inputs, outputs, and inventory changes . . .	Estimates and comparisons of inputs and outputs	Cost estimates
15	3.12. Material cost Cost for a substance that enters and/or leaves a quantity center. Material cost can be calculated in various ways, . . .	Any materials entering the quantity center counted as costs; choice over costing systems	Costing requirements
16	3.13. Material distribution percentage Proportion of the material inputs that flow into products or material losses.	Calculation and allocation of material costs	Cost estimates
17	3.14. Material flow Movements of material . . . between various quantity centers . . .	Definition of material flows	System requirements
18	3.15. Material flow cost accounting Tool for quantifying the flows and stocks of materials in processes or production lines in both physical and monetary units.	Definition of material flow cost accounting	System requirements
19	3.16. Material loss All material outputs, . . . except for intended products.	Definition of material losses	Costing requirements
20	3.17. Output Product, material loss, or energy loss that leaves a quantity center.	Spoilage as an output	Costing requirements
21	3.18. Process Set of interrelated or interacting activities that transforms inputs to outputs.	Manufacturing procedures (underlying the regulations)	Mission statement
22	3.19. Product Any goods or service.	Definition of finished goods	Costing requirements
23	3.20. Quantity center . . . which inputs and outputs are quantified in physical and monetary units.	Calculation of quantities and values (establishment of a quantity center)	Calculation methodology
24	3.21. System cost Cost incurred in the course of in-house handling of the material flows, . . .	Costs incurred by manufacturing procedures	Costing requirements
25	3.22. Waste management cost Cost of handling material losses generated in a quantity center.	Expenses for waste disposal	Costing requirements
26	4. Objective and principles of MFCA	Purpose of material flow cost accounting	Title
27	4.1. Objective . . . enhance both environmental and financial performance through improved material and energy use . . .	Manufacturing procedure improvement for energy efficiency and environmental protection (same purpose as green design)	Core concept
28	4.2. Principles	Illustrations	Title
29	4.2.1. Understanding material flow and energy use The flow of materials should be traced . . . where materials are stocked, handled, used, or transformed.	Tracing of the destination of materials	Core concept
30	4.2.2. Linking physical and monetary data . . . linked by the collection of data on the physical quantities of materials and energy use, and data on the associated costs.	Calculation of quantity and value based on the material low model	Cost estimates

Table A1. *Cont.*

No	Open Coding	Axial Coding	Selective Coding
31	4.2.3. Ensuring accuracy, completeness and comparability of physical data . . . be collected in consistent measurement unit or with sufficient conversion factors . . .	Quantifiable and measurable data	Consistent units
32	4.2.4. Estimating and attributing costs to material losses. . . . these costs should be attributed to the material losses that generated the costs, not to the products.	Material losses throughout the manufacturing process not to be added to products (different from traditional accounting)	Core concept
33	5. Fundamental elements of MFCA	Operations of material flow cost accounting	Title
34	5.1. Quantity center . . . material flows and energy use are quantified in quantity centers.	Key mechanism to uncover sources of waste (data sources)	Calculation methodology
35	5.2. Material balance . . . the physical inputs entering a system should be equal to the physical outputs from the system, . . .	Evaluation and calculation of inputs and outputs (efficiency measurement)	Core concept
36	5.3. Cost calculation	Costing basis and records	Title
37	5.3.1. General . . . material flow data should be translated into monetary units to support decision-making.	Consistent cost units and currency for quantities	Consistent units
38	5.3.2. Cost allocation . . . an appropriate allocation criterion should be selected that reflects as closely as possible the main driver for the costs being allocated.	Appropriate cost allocations	Costing requirements
39	5.3.3. Cost carryover between quantity centers The costs should be carried over and included as the costs associated with the input for the next quantity center.	Gradual additions of divisional costs as total costs	Costing requirements
40	5.3.4. Cost carryover of internally recycled material . . . the fact that materials need to be recycled points to inefficiencies in the original process.	Material recovery indicative of inefficient production	Green design required
41	5.4. Material flow model . . . providing an overview of an entire process and identifying the points where material losses can occur.	Illustration of material flows	Green design required
42	6. Implementation steps of MFCA	Implementation of material flow cost accounting	Title
43	6.1. General MFCA can provide significant information in various stages of the Plan-Do-Check-Act continual improvement cycle.	Meaningful information provided by material flow cost accounting (as its main purpose)	Precise green design required
44	6.2. Involvement of management To be effectively implemented, MFCA should be strongly supported by management.	Support from management required	System requirements
45	6.3. Determination of necessary expertise MFCA requires multiple types of expertise that can provide the diverse types of information needed for the analysis.	Knowhow in design, procurement, production, engineering, and environmental protection	Mostly skillsets in green design
46	6.4. Specification of a boundary and a time period . . . it is advisable to focus initially on a process or processes with potentially significant environmental and economic impacts. The period for data collection should be sufficiently long so as to allow meaningful data to be collected, . . .	Collection of cost data by defining the boundary and a time period	System requirements
47	6.5. Determination of quantity centers Various processes, . . . as well as material storage areas, can be considered as quantity centers.	Description of different types of quantity centers	Calculation methodology
48	6.6. Identification of inputs and outputs for each quantity center The inputs and outputs have been identified . . . that data from the quantity centers can be linked and evaluated across the entire system being studied.	Facilitation of links and evaluations	System requirements
49	6.7. Quantification of the material flows in physical units All physical units used should be convertible to a single standardized unit . . . all materials within the MFCA boundary should be traced and quantified, . . .	Consistent units for tracking and quantification	Consistent units
50	6.8. Quantification of the material flows in monetary units	Changes throughout manufacturing process to be quantified and converted to monetary terms	Consistent units

Table A1. *Cont.*

No	Open Coding	Axial Coding	Selective Coding
51	6.8.1. Material costs For each quantity center, the material costs for inputs and outputs, should be quantified. . . . the material inventory within the quantity center also should be quantified.	Detailed calculation of all the material inflow and inventory	Cost estimates
52	6.8.2. Energy costs . . . the costs of energy use should be quantified. . . . to allocate the total energy costs of the selected processes to the quantity centers.	Confirmation of the production procedures for energy consumption	Costing requirements
53	6.8.3. System costs The system costs associated with each quantity center should be quantified. . . . to allocate the total system costs of the selected processes to the quantity centers.	System cost allocation to respective quantity centers	Cost estimates
54	6.8.4. Waste management costs The waste management costs associated with each quantity center should be quantified. . . . should be attributed to the material losses leaving that quantity center.	Allocation of management expenses for waste disposal to respective quantity centers	Cost estimates
55	6.9. MFCA data summary and interpretation . . . review and interpretation of the summarized data will allow the organization to identify quantity centers with material losses . . . be analyzed in more detail to identify the root causes of the material losses and the associated factors that incur the costs.	Information to reveal the inefficient use of materials	Where green design is in demand
56	6.10. Communication of MFCA results Communicating the results to an organization's employees can be useful in explaining any process or organizational changes that will take place as a result of MFCA findings.	Findings from material flow cost accounting to inform stakeholders	Green design personnel
57	6.11. Identification and assessment of improvement opportunities . . . the organization may review the MFCA data and seek opportunities to improve environmental and financial performance.	Identification of cause for losses with the analysis based on material flow cost accounting	Green design required

Source: Compiled by this study.

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