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Integration of Material Flow Cost Accounting and Cleaner Production Technology in Achieving Sustainability: A Literature Review

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Abstract. *This paper presents a theoretical rationale for integrating the Model based on* ***Material flow cost accounting and Cleaner Production, and its role in achieving sustainability****. This study synthesizes theoretical and empirical evidence from several papers published in top-tier cost accounting and production management journals to develop a structured model of the integration process. The study concludes that MFCA is a significant predictor of performance efficiency and prerequisite ratios for production and corporate efficiency. It also highlights that Cleaner Production technology can enhance a company's environmental behavior and sustainable performance. The review identifies important shortcomings, such as the lack of longitudinal and cross-cultural research to utilise the merging approach between MFCA and CP technology to foster sustainability. It encourages research on both positive and negative dimensions to enhance sustainable organizational operations. Concrete suggestions are made on the industrial side to improve and accelerate the transition to more energy-efficient and sustainable production methods.*

Keywords: *Material Flow Cost Accounting, Cleaner Production Technology, Sustainability.*

1. INTRODUCTION

With the growing environmental and economic challenges facing industries worldwide, including in Iraq, there is a pressing need for modern management and accounting models that meet efficiency and sustainability requirements [1]. Traditional accounting systems are no longer able to provide comprehensive and accurate insights for measuring the true costs of production [2], particularly with respect to material and energy wastage and environmental impact [3]. Such inequity undermines the ability of economic agents to strike a balance between profit motives and environmental and social responsibility[4-5].

From this perspective, this research appears to be a genuine attempt to investigate current integrative processes that might help to improve the performance of industrial businesses. The study aims to determine the extent to which integrating material flow cost accounting and cleaner production technologies contributes to achieving sustainability.

The importance of this study is also demonstrated by its relevance as a serious attempt to investigate new mechanisms that contribute to improving the operation of industrial companies. The aim is to achieve product sustainability through the incorporation of MFCA and CP. As MFCA furnishes an analytical framework to account for materials and energy flows in a granular fashion and convert them into tangible financial figures, the tools of Cleaner Production provide operational measures and prevention mechanisms that eliminate waste and emissions at their root, thereby transforming the conventional linear industrial model into a long-term circular system.

This research aims to develop a theoretical basis for integrating Material Flow Cost Accounting with Cleaner Production tools and methods, and to examine their impact on achieving the three dimensions of sustainability: economic, environmental, and social.

Furthermore, it asserts that the paper seeks to fill a gap in the literature on how to integrate material flow cost accounting tools into cleaner production decision support and sustainability improvement.

2. LITERATURE REVIEW

2.1. Concept of Material Flow Cost Accounting (MFCA)

A New Management Concept for the Measurement, Analysis, and Disclosure of Costs for Environment-Oriented Management Accounting, Balancing Both Economy and Ecology. MFCA is an important tool for collecting information on material and energy flows and associated costs. It aims to promote environmental efficiency at economic cost by minimising raw material consumption and inducing corresponding performance improvements [6].

As a result of the development from its relatively recent origins in the late 90s, MFCA has been implemented very rapidly and widely at economic units (especially industrial ones) worldwide due to (i) depleting natural resources for material/energy sourcing, increasing prices thereof, and surging impacts therefrom on a global scale from industrial units like gas emissions/waste. The absence of information about these environmental costs has been harmful for the environment and society alike [7].

MFCA, also known as material and energy flow accounting or Flow cost accounting (FCA), is a method whose main objective is to trace the movement of materials and energy through a value-added system over a given period. It comprises the assessment of Cleaner Production opportunities at the process level and the calculation of preliminary waste treatment costs [8].

MFCA facilitates material flow analysis and decision-making to improve material and cost efficiencies by aligning well with economic objectives [9] and by contributing to more efficient use of materials through transparent enforcement of the physical and financial flows of materials.

The basic idea behind MFA is ‘material balance,’ which means input = output. MFCA defined inputs as everything required for fabrication, including raw materials (both primary and secondary), direct and indirect labor, water, electricity, and machinery. End products or final outputs are either positive (finished/semi-finished goods) or negative (waste resources or recycled materials) [10]. Positive products are being processed or have been processed, whereas negative products are waste or recycled material. The costs of inputs must be offset by the costs of outputs to monetize production. Therefore, the aggregate input price is the sum of the prices of positive outputs and negative outputs [11].

MFCA shows exactly where material flows at all stages of production are discharged throughout the life cycle of a product, how much material and energy are wasted, and where. This information can significantly help in making decisions to reduce costs and achieve competitive levels, as competition is one of the most fundamental principles that any economic unit should establish to remain viable or even thrive in the future. Certain scholars argue that MFCA is one of the most significant indicators of sustainability success and is also considered one of the main approaches adopted in AMAE [12].

Cecílio perceives MFCA as a flow-based accounting method that accounts for and measures all material and energy flows in both physical and monetary units. It also compares product prices and material waste [13]. Papaspyropoulos defines MA as a management accounting methodology that specialises in measuring and cost-justifying material and energy flows, attributing them to the responsible goods or services, and supporting solutions that minimise negative impacts while achieving cost savings [14]. Marota describes it as a management information system that identifies all inputs to the manufacturing environment and measures outputs and waste [15].

2.2. Concept of Cleaner Production

The first generation of Cleaner Production focused on eliminating waste in the production process. In contrast, more recent generations have evolved toward the policing of additional operational and resource-efficiency aspects. Cleaner Production can be applied throughout the product life cycle [16]. It is recognized as an integrated approach that encompasses changes at every stage of production, from raw materials processing and production through product design to end-of-life management of products or services. Cleaner Production is applicable across various sectors and scales, ranging from large-scale processing facilities to small- and medium-sized enterprises in manufacturing and service operations [17-18].

Various measures of Cleaner Production inherently augment productivity capacity, not only by covering the production commodities and techniques utilized by industrial enterprises, but also by extending to working conditions and workers' activities. This is intended to enable an individual to readily adopt a life that embodies Clean Production values as the best economic model, thereby delivering the maximum technical and economic profit [19].

According to Piprani et al. [20], Cleaner Production practices include examining a company's operational dimensions to identify potential areas for improvement in both its environmental and economic performance. Given the changing industrial landscape of the country, the joint implementation of green technologies, CP practices, energy efficiency, waste minimization, and sustainable performance in Iraq's manufacturing sectors would be a suitable context. For instance, as IQAir reports, Baghdad is the 50th most polluted city among the 125 cities assessed in the Global Air Quality Report (IQAir, 2024).

Therefore, for developing countries and those in transition economies, CP has been instrumental in promoting an alternative approach to waste management and resource conservation. The technique has enabled manufacturing industries to mitigate pollution hazards arising from waste and other emissions, making it an efficient way to better manage pollution. According to Gavrilescu, the continued adoption of CP technologies in the environmental sector, which is facing new challenges due to the expanded role of manufacturing industries, can enable companies to continue using available alternative approaches while reducing pollution from their plant activities [21].

De Oliveira Neto et al. [22] claim that Cleaner Production ensures that a manufacturing industry continues to integrate a continuous preventive environmental strategy into its production process, aimed at bolstering the company's productive efficiency and, at the same time, reducing the risk to individuals and the environment. In the manufacturing industry, the integration of cleaner production necessitates the responsible use of raw materials and energy, the adoption of safe production methods that minimize or eliminate hazardous materials, and the generation of lower quantities and lower-quality waste while managing less-toxic operational waste.

In the hotel industry, Cleaning Production practices can be introduced, and the concept, which offers multiple advantages to its practitioners, serves as an incentive for hotel managers who wish to maintain the overall appearance of their properties while establishing a positive image and promoting positive public relations by marketing it as environmentally friendly. This leads to high customer demand [23]. For additional financial benefits, implementing Cleaner Production may be considered a reasonable investment for hotel proprietors [24].

In the restaurant and food industry, it is estimated that more than 30% of food produced globally is wasted or lost, according to the Food & Agriculture Organization of the United Nations—a problem occurring at a time when nearly one billion people are hungry; this is fundamentally wrong. Food loss and waste are misuses of labor, water, energy, land, and agricultural inputs used in their production [25].

Cleaner Production, according to Da Silva & Gouveia, is "the adoption of techniques that reduce the use of natural resources and apply new technologies to achieve the maximum efficiency in the cycle of products". This involves reducing emissions from the manufacturing or use of the product, whether from water, air, or ground impacts, and creating products that last for a long period and can be kept or recycled if possible, aiming at production with reduced energy use [16]. Hadibarata & Chia designate it as the set of approaches that use natural resources in the most efficient way at all stages of production, rendering the product environmentally friendly through low-energy utilization and being amenable to recovery and recycling processes [26]. He regards it as a comprehensive "prevention approach" in which waste and emissions are minimized, and resources are used as efficiently as possible in industrial processes [27].

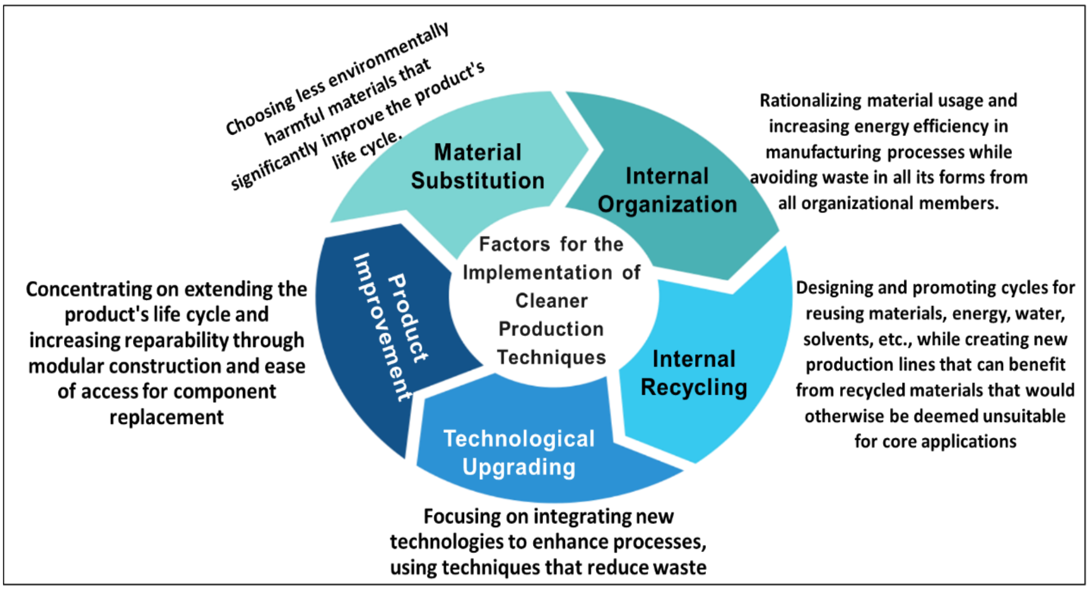
2.3. Factors for the Implementation of Cleaner Production Techniques

Five key success factors are relevant to the implementation and utilisation of Cleaner Production, as indicated by Nilsson [28]. They may be classified under the following heads:

1. Substitution: If possible, attempt to find raw materials that are not at a high risk of being mined unsustainably, and/or those that more easily improve the life cycle of your product. This transformation must be based on the product's raw materials and on auxiliary or working materials used in its production. According to Ogunseitan & Schoenung [29], the first objective when choosing conventional materials for product manufacturing is to “connect material with purpose”. This can be achieved by focusing on material properties such as mechanical, thermal, electrical, optical, and chemical performance, together with processability, production cost, availability to the end user, and environmental impacts. Ideally, these are also quantifiable characteristics that designers can use to sort and classify appropriate material alternatives based on the material's functions and properties.
2. Internal to the Organization: A material reduction, use Rationalization and efficiency improvement of energy use in the manufacturing process, Waste minimization in all its intrinsic forms from every organizational member. Workers generate large quantities of waste, which can be productivity-damaging and hazardous. Rahim et al. [30] indicate that appropriate employee training across multiple areas is an important factor in enhancing performance. Educating stakeholders is important when implementing MIPS [31] or when introducing changes to the organization's design and operation. Conversations with production workers can generate ideas to improve the product through changes to the production process, and conversations with safety team members can help prevent on-site hazards.
3. Closed-loop Recycling: Developing and facilitating closed loops to recycle materials, energy, water, solvents, etc., by developing new products that can benefit from recycled raw material not suitable for the core product. Such an operation requires more efficient water use and minimizes waste, thereby offering economic advantages. To implement on-site recycling, it is necessary to transition from a linear economy to a circular economy by closing the production loop. Gavrilescu et al. [32] point out that in this production track, products are gathered at the end of their product life, along with production waste such as leftover parts and scraps, which can be remade or recycled, thereby improving material efficiency, reducing costs, and

enhancing environmental performance in industrial companies. The avoidance of numerous negative environmental consequences that would otherwise arise from emissions, waste, energy use, and transportation packaging can be very high when industrial facilities implement a tight closed-loop production system [33]. This not only minimizes the environmental effects of such actions but also supports economically informed decision-making aimed at applying life-cycle cost analysis when implementing similar activities.

4. Technology Upgradation: With an emphasis on the adoption of new technology to improve processes in a manner leading to minimal waste and lower gaseous emissions, liquid effluents, and being eco-friendly and less hazardous to the work environment. New technologies introduced can increase productivity [34], reduce material waste, and generate waste and energy. These emerging technologies can be integrated into existing systems as a layer on top, as supporting technologies, or as partially or fully replacing systems to improve the organization's production processes [30].
5. Product Improvement: Focusing on elongating the product's life by increasing repairability on the product level with modularization and accessibility of components, designing for ease of remanufacturing or recycling, as well as avoiding substances [35]. A study by Schomberg et al. [36] also noted that a modular product structure offers opportunities to maintain and replace defective elements within corresponding units, thereby increasing the product's service life. For example, modular handheld devices have been shown to emit up to 40% less and to conserve substantial reserves of raw materials compared with conventional designs. These facts can be represented by Fig. 1 as follows:



. Figure 1 illustrates the factors for the Implementation of Cleaner Production Techniques.

3. MATERIALS AND METHODS

To promote transparency, accuracy , and completeness in writing the review, during the data collection stage, we included items aligned with the PRISMA 2020 guidelines. Such a standard is widely employed in academic research, including that from the social, administrative, and medical sciences [37]. Articles were also reviewed after applying exclusion criteria, such as titles that did not contain "orientation in Material Flow Cost Accounting" or "Cleaner production."

Data acquisition procedures were based on well-established scientific databases such as Scopus, Clarivate, and Google Scholar, which are known to host the global body of scientific literature. The data collection took 14 months.

To minimize bias and error, the key search terms “Material flow cost accounting” and “Cleaner production technology” were used, complemented by specific keywords such as sustainability and company performance. Inclusion criteria were English-language research papers and systematic reviews published between 2015 and 2025.

4. RESULTS AND DISCUSSION

4.1. RESULTS

In a case study of KwaZulu-Natal conducted by Doorasamy [38], the composition of boiler ash analysed showed that, on average, about 20% of the coal input was lost as unburned coal, present as it was in the beet stukke (solid waste). This was reported by chemical analysis of boiler ash formed during steam production (carbon content approximately 20%). Inefficient production processes resulted in significant environmental and economic losses for the company, which incurred approximately 100,375 US$ (South African) in losses during the financial year in question. The average amount of coal wasted without contributing to steam generation was 20%, representing a WPC with a material value of $780,191.01 (USD).

In another study by Andini et al. [39], purposive sampling was used to examine 81 manufacturing companies in the basic materials sector that were listed on the Indonesia Stock Exchange in 2021–2023. A multiple linear regression analysis revealed that MFCAs were the most significant determinants of corporate sustainability.

Holiawati et al. [40] investigated a sample of 47 firms in the energy industry over two years (2022 to 2023). Using panel data regression to test the hypothesis, the results indicate that the Material Flow Cost Accounting (MFCA) system has a positive effect on environmental performance, with a significant effect ($p < 0.05$). The coefficient and p-value are 0.061 and 0.013, respectively. The MFCA approach enhances resource utilization efficiency and reduces the generation of waste and hidden costs in production operations.

Furthermore, Obaid [41] conducted a study on the restriction of Cleaner Production in the context of 500- and 1000-kVA electric generators. The factory earns $450,000 per year from selling recycled metal waste, with 1.5 tons sold at $300,000 per ton. Cleaner Production implementation represents a significant paradigm shift in industry, particularly in the electrical generator market. It offers numerous competitive advantages by improving product quality, efficiency, and profitability, reducing costs, and increasing sales. It also contributes to environmental conservation, including waste reduction and zero emissions.

4.2. DISCUSSION

Maintaining current technological levels will reduce losses and increase efficiency, with non-product-related production cost savings estimated at $632,016.53 per annum. The physical and monetary data systems are significantly disconnected, impeding full environmental cost management. This highlights the important role of communication and the integration of environmental accounting [38].

The investigation by Holiawati et al. [40] empirically confirms that, by examining operational cash flows, we can contribute to improving environmental performance in the energy industry. The findings suggest that operational transparency and waste reduction (through operational cash flow analysis) are more important than reporting transparency (via green accounting) for achieving sustainability.

The use of MFCA increases transparency in material and energy flows and helps identify waste and cost inefficiencies. The study by Andini et al. [39] empirically finds that green accounting and PRPI 29/fiscal compliance tax law for the manufacturing industry/cost system control on sustainability have a significant bearing on the declaration of financial statements about corporate sustainability among manufacturing firms.

Cleaner Production addresses environmental pollution and, at the same time, concerns economic efficiency and sustainability in production processes. Cleaner production methods are emerging approaches used to control industrial pollution. They are of great economic value in facing up to the environmental pollution challenges and mitigating their effects [41].

5. CONCLUSIONS

The integration of Material Life Cycle Analysis with Cleaner Production offers a solid framework for sustainable manufacturing, transforming environmental challenges into economic opportunities. This approach shifts waste from being an invisible cost to a clear objective for efficiency enhancement, thereby supporting profitability and sustainability in resource-intensive industries.

The integration of Material Flow Cost Accounting (MFCA) and Cleaner Production (CP) represents an effective blend of managerial accounting and production practices. MFCA serves as a diagnostic tool that identifies and economically validates improvement opportunities, while CP provides corrective technological solutions. Their combination converts sustainability from a conceptual goal into a data-driven process focused on continuous economic and environmental improvements, ultimately enhancing product sustainability.

The current study recommends developing standardized applied models and a streamlined framework for Material Flow Cost Accounting tailored to priority sectors such as hotels, hospitals, and resource-intensive manufacturing industries. This should focus on simplifying the steps for identifying "quantity centers" and collecting physical and financial data. Moreover, further research is needed on the intersections and integration between Cleaner Production tools and Lean Production principles, particularly in waste elimination. MFCA can provide precise quantitative and monetary measurements of the seven types of waste, enhancing the effectiveness of continuous improvement initiatives. To facilitate the successful implementation of MFCA and CP, comprehensive programs for managing organizational and cultural change should be established. These programs must focus on training and qualifying management accountants, engineers, and production managers together, thereby creating a common language and an integrated understanding of the technical and financial dimensions essential for improving efficiency.

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