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Environmental Cost Accounting in the Sugar Industry: An MFCA Perspective on "Sweet" Environmental Burdens

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Abstract: In recent years, environmental protection has become an indispensable component of China's economic development, with its significance increasingly emphasized. National efforts towards environmental governance have expanded from traditional high-pollution industries to encompass all sectors with potential environmental impacts, demonstrating a comprehensive and multi-layered commitment to environmental management. However, within the domain of environmental cost accounting, research and practice have predominantly concentrated on traditional heavy industries such as coal and chemical sectors, leaving a gap in other industries, particularly in light industries such as the sugar industry. Given that the sugar industry is one of the top ten water polluting industries in China, it is particularly necessary to explore its environmental cost accounting. One side, this study addresses this gap by shifting the research focus to the sugar industry, thereby broadening the scope of environmental cost accounting. On the other side, utilizing Material Flow Cost Accounting (MFCA), this research quantifies the environmental costs incurred during the sugar production process, applying its accounting principles to divide materials in enterprise production activities into positive and negative products, elucidating the extent of environmental pollution and resource wastage. This approach not only enhances corporate environmental responsibility but also provides practical insights for the sustainable development of the industry and the formulation of governmental policies.

Keywords: Sugar industry; Environmental cost accounting; Material Flow Cost Accounting (MFCA); Negative product; Sustainable development

1 Introduction

The sugar industry is a fundamental sector within the food industry and serves as a raw material industry for various products such as food, chemicals, and fermentation products, holding a significant position in the national economy. However, its environmental issues have long been overlooked. Research has found that the sugar industry is one of the industries with severe organic pollution within the light industry sector. The wastewater generated during production contains a large amount of organic matter and sugars, with high Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD) levels. A sugar factory processing 2,000 tons of beets per day discharges wastewater with a BOD equivalent to the sewage pollution of a city with a population of 250,000. Thus, it is evident that while the sugar industry brings sweetness to people, it also faces environmental pollution challenges. Therefore, environmental factors should be incorporated into the cost accounting of the sugar industry.

China's current resource and environmental management system, though reliant on mandatory environmental information disclosure, environmental tax collection, and environmental pollution punishment systems enforced by the state, still shows a reactive approach to some extent. Most sugar enterprises' consideration of environmental costs remains focused on pollution control for already occurred outcomes, such as the treatment for compliant wastewater discharge, lacking proactive strategies for resource efficiency improvement and minimization of environmental impact. Against this backdrop, MFCA, as an advanced environmental cost accounting tool, can clearly reflect the cost consumption situation in each production process and promote pollution reduction from the source. Therefore, this paper constructs an environmental cost accounting system based on MFCA through specific case studies, supplementing the internal environmental cost data of enterprises. Analyzing the results with the intention of exploring strategies for controlling environmental costs in the sugar industry. This enables similar sugar industries to understand the basic application process of MFCA and use this method to actively consider environmental costs, further promoting the sustainable development of the industry.

2 Literature Review

2.1 Relevant Research on Environmental Cost Accounting

Research in the field of environmental cost accounting in China began in the 1990s, when Professors Ge and Li [1] jointly published a paper introducing the concept of green accounting into the domestic academic community for the first time, marking the beginning of environmental accounting research in China. Since then, numerous scholars have conducted extensive and in-depth explorations around the definition of environmental costs, accounting methods, and tools. At the methodological level of environmental cost accounting, scholars have gradually realized that the traditional cost accounting system is inadequate to fully reflect the true impact of business activities on the environment. Therefore, various methods and tools in environmental management accounting, such as Activity-Based Costing, Full Cost Accounting, MFCA, and Total Cost Assessment, have been applied to environmental cost accounting in order to provide more accurate cost information [2]. Olba-Zięty et al. [3] believe that the current research trend tends to explore more comprehensive and forward-looking methods for measuring and recognizing environmental costs, to ensure that companies can comprehensively assess and report their impact on the environment, including not only internal costs but also potential external impacts.

In recent years, with the rise of the circular economy concept, the research perspective of environmental cost accounting has further broadened. Professors Xiao and Zeng [4] combined MFCA with circular economy theory and innovatively proposed the concept of Resource Value Flow Accounting. This theory not only emphasizes the economic value of waste recycling but also provides new ideas and practical paths for environmental cost management, especially in terms of environmental cost management from the perspective of waste recycling, offering valuable theoretical support and practical experience. Japan is one of the beneficiaries of MFCA, with hundreds of companies implementing MFCA by 2009, further consolidating its position as a core method of environmental management accounting [5].

In summary, the research goal of environmental cost accounting is to construct a comprehensive framework that helps enterprises make substantial progress in identifying, measuring, and managing their environmental impacts, thereby promoting the transition of the economic model towards sustainability.

2.2 Relevant Research on MFCA Theory and Application

MFCA, as a relatively new environmental accounting management tool, did not originally stem from accounting theory but from environmental management. It originated from the internal environmental management project of Kunert Company in Germany, which evaluated and managed environmental costs through material balance analysis [6]. In China, the theoretical system and practical exploration of MFCA can be traced back to the pioneering work of Professor Feng [7] from Nanjing University. Professor Feng [7] not only introduced this cutting-edge environmental accounting tool into China but also conducted systematic localized research and promotion, laying a solid foundation for the construction of China's MFCA theoretical system. Subsequently, the interest in MFCA from the domestic academic and practical circles has been increasing, with research results becoming increasingly abundant. Professors Deng and Lu [8] pointed out in their research that, in the face of new challenges and opportunities, traditional cost accounting methods have shown limitations, especially in terms of environmental cost accounting, where their accuracy and practicality need improvement. In contrast, MFCA, with its unique perspective and methods, can accurately identify the stages of production with severe resource losses, effectively reduce material waste, thereby achieving a win-win situation for both economic and ecological benefits [8].

Regarding the specific application of MFCA, scholars have extensively discussed its applicable scenarios and effectiveness. Xu [9] extended the concepts of "resource flow" and "material flow" to the steel industry, taking Nanjing Iron and Steel Co., Ltd. as a research object, and conducted a detailed analysis of the costs at various stages of steel production, providing the industry with a refined cost control perspective. Meanwhile, in the application cases of India, it has also been found that MFCA can not only reduce waste, but also improve financial and environmental performance [10]. In recent years, MFCA as a powerful tool for refined carbon cost accounting, has garnered extensive attention from both academia and industry [11]. For Thailand, one of the developed countries where MFCA is widely used, some scholars conducted regression analysis using survey data and concluded that MFCA can effectively reduce environmental resource waste [12], Santoki et al. [13] demonstrated the applicability of MFCA in ceramic industries, establishing techniques to reduce losses and improve production processes based on MFCA analysis, encouraging other small and medium enterprises to apply MFCA methods to enhance manufacturing system performance. Ho et al. [14] introduced MFCA into sewage treatment plants, improved sewage treatment processes, established a sewage discharge matrix, and thus established a wastewater treatment model.

After the extensive applicability of MFCA was verified, the combination of MFCA with other methods also showed excellent results. For example, Dekamin et al. [15] integrated MFCA with Life Cycle Assessment (LCA), providing a detailed environmental cost analysis framework for small and medium enterprises, assisting them in achieving green transformation. The data analysis method used by Fitriani et al. [16] is multiple linear regression analysis. Exploring the impact of implementing green accounting and MFCA on the value of manufacturing enterprises, the results show that higher levels of green accounting increase company value, and MFCA also shows a significant positive correlation with company value. In summary, the above researches show that using the MFCA method can make the internal resource loss costs explicit, helping enterprises improve resource utilization [17], MFCA can handle the material and financial flows within a company, reduce the environmental impact of waste generated by the enterprise [18], receive unanimous praise for improving production processes, and provide new ideas for managers' decision-making [19], and incorporating by-products into cost calculations can reflect the true production costs of enterprises, playing a key role in energy conservation and emission reduction.

In conclusion, on the one hand, the research on MFCA in China started relatively late, and current application cases of MFCA in China are relatively limited, but more and more scholars believe that future cost measurement models need to introduce MFCA [20], and relevant indicators need to be established for quantitative analysis, making abstract resources more intuitive, indicating a great potential for MFCA's future development in China [21]. On the other hand, most current application cases are concentrated in traditionally high-pollution industries such as metallurgy and chemicals, which to some extent limits the broad application and development of MFCA theory. However, since China officially released the MFCA General Guidelines in 2020, this situation has been gradually improving. With the significant expansion of MFCA's applicability, as long as production activities involve the use of materials and energy, regardless of industry attributes, MFCA can be adopted for environmental cost accounting, undoubtedly paving new paths for the popularization and deepening application of MFCA in China.

Based on this background, this paper shifts the research focus to the sugar industry, aiming to deepen the exploration of environmental costs in polluting industries through the perspective of MFCA within the framework of sustainable development, expand the application boundaries of MFCA, reveal the main stages of resource wastage in the sugar production process, and propose targeted improvement suggestions, promoting the optimization of enterprise resource utilization and the sustainable development of the industry.

3 Design of Environmental Cost Accounting System Based on MFCA for D Sugar Industry

The D Sugar Industry Co., Ltd. is currently the largest beet sugar enterprise in Heilongjiang Province of China, the largest beet sugar producer and supplier in the three northeastern provinces of this country, and a key leading enterprise in agricultural industrialization in Heilongjiang. After conducting a field investigation of D Sugar Industry, it was found that there are some areas for improvement in environmental cost accounting.

Specifically, the company has not yet established dedicated environmental cost accounts, nor has it conducted independent measurement and accounting. Currently, the financial department still follows traditional methods, confirming and measuring environment-related cash outflows and inflows, and recording them through detailed accounts such as secondary accounts under the original basic accounts. However, this approach ignores indirect environmental costs and opportunity costs, failing to deeply explore the root causes of cost generation. Consequently, it is impossible to comprehensively analyze the details of environmental cost losses, and thus, the actual resource consumption of the enterprise cannot be accurately grasped.

To address this issue, it is particularly important to introduce MFCA for environmental cost accounting. The essence of MFCA lies in the detailed division of various material centers and the quantitative analysis of material resource flow efficiency, accurately identifying optimization points in environmental cost management. As shown in Figure 1, the basic path of systematic accounting using MFCA by the enterprise helps the enterprise accurately control environmental costs and effectively promote sustainable development strategies.

The first step is to clarify the accounting objects based on the company's products. In the preparation stage, it is necessary to determine the accounting objects for applying the MFCA method according to the company's products, whether it is for a single process or multiple processes, and whether it is for a single enterprise or the entire supply chain.

The second step is to determine the material centers. After determining the implementation objects, analyze the composition of material flow costs and determine the material centers following the principle of economic efficiency. In addition, it is necessary to determine the company's existing cost accounting methods, collect and organize data for the selected accounting period.

The third step is to classify the company's costs based on the MFCA framework. Classify the cost data collected in the previous step into material costs, system costs, and energy costs, and aggregate the cost data.

The fourth step is to calculate the positive and negative products of each material center. According to the operational principles of MFCA, perform specific calculations, establish a material flow cost matrix, and allocate the positive and negative product rates.

The fifth step is to analyze the accounting results of MFCA. Based on the accounting results, analyze them in conjunction with the company's actual production and operation situation, identify the processes that need improvement, and propose improvement suggestions.

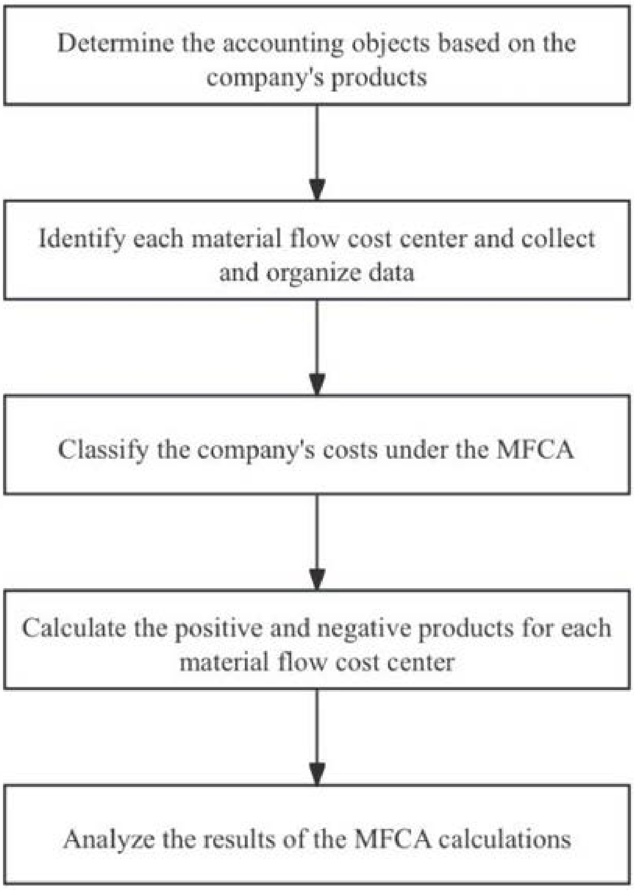

Figure 1. Steps for applying MFCAs

3.1 Clarifying the Accounting Objects

For D Sugar Industry, adopting the MFCA accounting model requires first selecting a product line with a large proportion of the main business income and significant growth potential in customer orders. This allows for the achievements to be promoted across all product lines of the enterprise. It is known that more than half of the company's economic sources come from the "Hongguang Brand White Granulated Sugar," which is the designated production sugar for well-known domestic and international companies such as Nestlé, Coca-Cola, Yili, Mengniu, and Harbin Pharmaceutical Group. The main business income proportion is large, and the order volume is relatively stable. Therefore, for the company, it is appropriate to select "Hongguang Brand White Granulated Sugar" for environmental cost accounting.

3.2 Division of Material Centers and Data Organization

(1) Division of Material Centers

In the production process, D Sugar Industry mainly adopts the carbonation method for direct production of white sugar. The production process is divided into four stages: extraction, clarification, crystallization, and packaging (Figure 2). The extraction process primarily involves cleaning the beets entering the factory, cutting them into L-shaped strips with a slicer, continuously feeding them into an extractor for countercurrent diffusion with hot water to dissolve the sugar and some non-sugars into the water, resulting in extraction juice. The clarification process involves pre-liming and main liming treatment with lime milk from a lime kiln, followed by a two-carbonation purification process, and then sulfur bleaching with SO_2 to obtain clear juice. The crystallization process first requires further concentration of the syrup pumped from the clarification process to crystallize into sugar paste, which is then unloaded into the crystallization tanks and separated into molasses and sugar paste through centrifugation. The resulting granules are the ordinary white granulated sugar. The packaging process involves drying the sieved white granulated sugar to reduce moisture content, then sieving to achieve the desired granule size and packaging the white granulated sugar into bags, becoming the finished product stored in the warehouse.

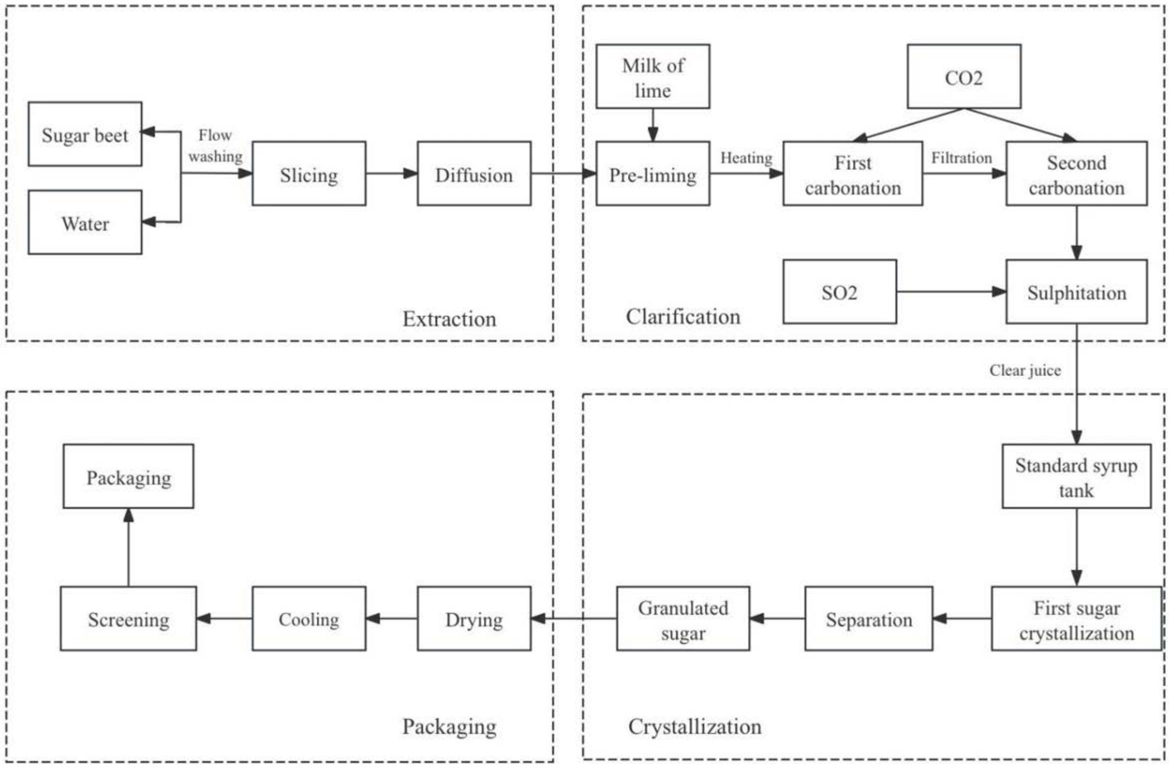

Figure 2. Division of material centers

(2) Data Organization

Through field investigation of D Sugar Industry, it was found that the current cost accounting method used by D Sugar Industry is the traditional cost accounting method (taking Hongguang Brand White Granulated Sugar as an example), which mainly focuses on post-event accounting. The production cost of sugar in 2023 includes three main categories of cost data: direct materials, direct labor, and manufacturing expenses. The summary of various cost inputs is shown in Table 1, with a total product cost of 89,265,338.05 yuan. Given the known production volume of 14,420.7 tons, the unit cost is approximately 6,190.08 yuan/ton. However, according to the current cost accounting method, the existing production cost data can only reflect information on the total production cost, unable to provide specific cost information for each production stage. Consequently, it is not possible to identify and improve stages with high resource consumption and low production efficiency, presenting certain drawbacks.

Table 1. Summary of the company's 2023 production cost data (Unit: Yuan)

Direct Materials		Direct Labor	Manufacturing Expenses	
Beets	64,710,303.36		Water and Electricity Fees	611,674.25
Raw Coal	8,522,327.09		Fixed Asset Depreciation	2,772,620.43
Limestone	926,323.61		Inspection and Testing Fees	174,487.91
Coke	1,083,249.74		Transport and Loading Fees	77,849.06
Filter Cloth	254,626.66	5,652,386.25	Routine Maintenance Expenses	441,771.72
Sugar Bags	585,321.29		Technical Transformation and Overhaul Expenses	424,414.53
Other Materials	2,077,717.71		Other Manufacturing Expenses	112,837.58
Water Resource Fee	58,051.00		Safety and Environmental Protection Expenditures	10,834.91

Company's 2023 Annual Report and Internal Data.

3.3 Cost Classification of Material Centers

Based on the above production process, the material centers are divided into the Extraction Center, Clarification Center, Crystallization Center, and Packaging Center. Using the specific methods of MFCA, the original cost data are classified into three main categories: material costs, energy costs, and system costs. Material costs are the costs of input raw materials and auxiliary materials used in production, mainly including beets, process water, limestone, filter cloth, dissolved sugar, and sugar bags, etc. (see Table 2). Energy costs include energy sources such as raw coal, coke, water, and electricity (see Table 3). System costs are the costs incurred internally by the enterprise to support and maintain production, mainly including employee wages, equipment depreciation, and other manufacturing expenses for daily consumption, such as periodic replacement parts (see Table 4). The calculation method used for Minor material cost is unit price * quantity, while system cost and energy cost mainly adopt the cost collection and allocation method of two parts.

Table 2. Enterprise material costs (Unit: Yuan)

Material Center	**Material Cost**			
	Name	Unit Price	Quantity (tons, bags)	Cost (yuan)
Extraction Center	Sugar beets	520 yuan/ton	124,442.89 tons	64,710,303.36
	Process water	0.4 yuan/cubic meter	145,127.5 cubic meters	58,051.00
Clarification Center	Limestone	150 yuan/ton	6,175.49 tons	926,323.61
	Filter cloth	2,600 yuan / set	97.93 sets	254,626.66
Crystallization Center	Other materials	-	-	2,077,717.71
Packaging Center	Sugar bags	2 yuan/bag	292,661 bags	585,321.29

Table 3. Enterprise energy costs (Unit: Yuan)

Material Center	**Energy Cost**			
	Raw Coal	Coke	Water and Electricity	Total
Extraction Center	9,253,573.38	115,790.45	245,281.37	9,614,645.21
Clarification Center	13,848,004.92	185,264.72	214,085.99	14,247,355.63
Crystallization Center	36,949,583.22	578,952.26	91,751.14	37,620,286.61
Packaging Center	4,659,141.84	46,316.18	60,555.75	4,766,013.77
Total	64,710,303.36	926,323.61	611,674.25	66,248,301.22

Table 4. Enterprise system costs (Unit: Yuan)

Material Center	**System Cost**			
	Labor Cost	Depreciation	Others	Total
Extraction Center	800,047.34	540,812.23	174,288.68	1,515,148.25
Clarification Center	1,179,758.16	1,531,884.91	257,007.90	2,968,650.97
Crystallization Center	3,320,288.14	466,057.61	723,317.99	4,509,663.74
Packaging Center	352,292.61	23,892.08	76,746.21	452,930.92
Total	5,652,386.25	2,562,646.83	1,231,360.8	9,446,393.88

3.4 Calculation of Positive and Negative Products for Each Material Center

Within the production chain of the enterprise, each material center serves as a node in the production process, bearing the functions of material input and output. The outputs of these centers are classified into positive products and negative products. Positive products refer to those directly satisfying the enterprise's production goals, having commercial value or utility, and continuing to flow into subsequent production stages. Negative products encompass waste, pollutants, and other undesired outputs generated during the production process that do not proceed to subsequent stages. Based on the cost flow of each material center, the total costs (current inputs + initial or previous material center inputs) are allocated between positive and negative products. The allocation ratios of positive and negative product costs are calculated using the following formulas:

Positive product cost ratio = Positive product cost / (Current inputs + Initial or previous material center inputs)

Negative product cost ratio = Negative product cost / (Current inputs + Initial or previous material center inputs)

(1) Calculation of Positive and Negative Product Ratios for Material Costs in Each Material Center

Collect positive and negative product costs based on the resource utilization of raw materials, and calculate the proportion of positive and negative product costs for material costs. The material cost allocation table is shown in Table 5.

Table 5. Distribution of material costs

Material Center			Material Costs	Ratio
Extraction Center	Input	Initial	-	-
		Current Inputs	64,768,354.36	-
	Output	Positive Products	33,420,470.85	51.6%
		Negative Products	31,347,883.51	48.4%
Clarification Center	Input	Previous Stage Inputs	33,420,470.85	-
		Current Inputs	1,180,950.27	-
	Output	Positive Products	13,875,169.87	40.1%
		Negative Products	20,726,251.25	59.9%
Crystallization Center	Input	Previous Stage Inputs	13,875,169.87	-
		Current Inputs	2,077,717.71	-
	Output	Positive Products	12,746,357.18	79.9%
		Negative Products	3,206,530.40	20.1%
Packaging Center	Input	Provious Stage Inputs	12,746,357.18	-
		Current Inputs	585,321.29	-
	Output	Positive Products	13,011,718.19	97.6%
		Negative Products	319,960.28	2.4%

(2) Calculation of Positive and Negative Product Ratios for Energy Costs in Each Material Center

In sugar production, the consumption of materials and energy typically occurs concurrently. This means that both raw material processing and product refinement require corresponding energy support. For instance, processes such as sugarcane pressing, syrup evaporation and concentration, and sugar crystal crystallization all necessitate energy consumption, such as steam or electricity. Therefore, the calculation of energy costs will follow the positive and negative product rates of material costs in each material center (see Table 6).

Table 6. Energy cost allocation

Material Center	Costs to be Allocated	Product Type	Percentage	Allocated Costs
Extraction Center	9,614,645.21	Positive Product	51.6%	4,961,156.93
		Negative Product	48.4%	4,653,488.28
Clarification Center	14,247,355.63	Positive Product	40.1%	5,713,189.61
		Negative Product	59.9%	8,534,166.02
Crystallization Center	37,620,286.61	Positive Product	79.9%	30,058,609.00
		Negative Product	20.1%	7,561,677.61
Packaging Center	4,766,013.77	Positive Product	97.6%	4,651,629.44
		Negative Product	2.4%	114.384 .33

(3) Calculation of Positive and Negative Product Ratios for System Costs in Each Material Center

Generally, enterprises calculate system costs based on loss rates or operation rates. However, due to the seasonal production nature of D Sugar Industry, which operates at full capacity for 24 hours a day in November and December following the October opening, system operational loss rates are ignored. Instead, cost accounting is conducted based on the positive and negative product ratios of material costs in each material center (see Table 7).

Table 7. System cost allocation

Material Center	Costs to be Allocated	Product Type	Percentage	Allocated Costs
Extraction Center	1,515,148.25	Positive Product	51.6%	781,816.50
		Negative Product	48.4%	733,331.75
Clarification Center	2,968,650.97	Positive Product	40.1%	1,190,429.04
		Negative Product	59.9%	1,778,221.93
Crystallization Center	4,509,663.74	Positive Product	79.9%	3,603,221.33
		Negative Product	20.1%	906,442.41
Packaging Center	452,930.92	Positive Product	97.6%	442,060.58
		Negative Product	2.4%	10,870.34

(4) Overall Accounting Results

Based on the above steps, the total material flow cost matrix for D Sugar Industry based on MFCA is calculated. According to Table 8 the unit sugar cost is approximately 4,466.76 yuan per ton. The calculation formula is:

Unit Sugar Cost = (Packaging Center Positive Product Material Cost + Sum of Positive Product Energy Costs of all Material Centers + Sum of Positive Product System Costs of all Material Centers) / Production Quantity

= (13,011,718.19 + 45,384,584.98 + 6,017,527.45) / 14,420.7 = 4,466.76 yuan/ton

Table 8. Material flow cost matrix (Unit: Yuan)

Item Cost		Extraction Center	Clarification Center	Crystallization Center	Packaging Center
Current Material Center Inputs	Material Cost	64,768,354.36	1,180,950.27	2,077,717.71	585,321.29
	Energy Cost	9,614,645.21	14,247,355.63	37,620,286.61	4,766,013.77
	System Cost	1,515,148.25	2,968,650.97	4,509,663.74	452,930.92
	Total	75,898,147.82	18,396,956.87	44,207,668.06	5,804,265.98
Transferred from Previous Material Center	Material Cost	-	33,420,470.85	13,875,169.87	12,746,357.18
	Energy Cost	-	4,961,156.93	5,713,189.61	30,058,609.00
	System Cost	-	781,816.50	1,190,429.04	3,603,221.33
	Total	-	39,163,444.28	20,778,788.52	46,408,187.51
Total	Material Cost	64,768,354.36	34,601,421.12	15,952,887.58	13,331,678.47
	Energy Cost	9,614,645.21	19,208,512.56	43,333,476.22	34,824,622.77
	System Cost	1,515,148.25	3,750,467.47	5,700,092.78	4,056,152.25
	Total	75,898,147.82	57,560,401.15	64,986,456.58	52,212,453.49
Positive Products	Material Cost	33,420,470.85	13,875,169.87	12,746,357.18	13,011,718.19
	Energy Cost	4,961,156.93	5,713,189.61	30,058,609.00	4,651,629.44
	System Cost	781,816.50	1,190,429.04	3,603,221.33	442,060.58
	Total	39,163,444.28	20,778,788.52	46,408,187.51	18,105,408.21
Negative Products	Material Cost	31,347,883.51	20,726,251.25	3,206,530.40	319,960.28
	Energy Cost	4,653,488.28	8,534,166.02	7,561,677.61	114,384.33
	System Cost	733,331.75	1,778,221.93	906,442.41	10,870.34
	Total	36,734,703.54	31,038,639.20	11,674,650.42	445,214.95

4 Analysis of Accounting Results

4.1 Analysis of Negative Products by Cost Type

Based on the total negative product costs in different cost types as mentioned above, the proportion of material cost negative products reaches as high as 69.20%, as shown in Table 9, this is closely related to the nature of the enterprise, as D Sugar Industry is an agricultural processing company, which involves substantial use of sugar beets in the pressing process. The inherent biological characteristics of sugar beets and physical changes during pressing lead to a certain proportion of material loss. Traditional pressing processes often result in sugar residue remaining in the pulp, increasing material loss. Aging, wear, or improper maintenance of pressing equipment also decrease efficiency, contributing to further material loss. Post-pressing, substantial fiber residue is generated. Although D Sugar Industry currently sells the residual granules as animal feed, there remains room for improvement in sugar extraction efficiency and reduction of material loss.

Table 9. Analysis of negative product costs by cost type (Unit: Yuan)

	Material Cost	Energy Cost	System Cost	Total
Negative Cost	55,600,625.44	20,863,716.24	3,428,866.43	80,352,042.38
Percentage	69.20%	25.97%	4.27%	100.00%

4.2 Analysis of Negative Products from the Perspective of Each Process Center

Calculating the ratio of resource loss costs for each process center to the total resource loss costs sequentially, as shown in Table 10, it can be observed that the majority of resource loss costs are concentrated in the extraction and clarification centers. In the extraction center, material cost losses primarily dominate negative products, while the clarification center exhibits a higher proportion of energy-related negative products. This is mainly due to the current sugar factory's continued use of traditional methods in critical production processes such as clarification, where limestone is heated to generate CO_2 for filtration. Although mature, this process requires substantial thermal energy to sustain reactions, leading to significant energy losses in the generation and transmission process, thus lowering energy efficiency. Furthermore, this method can generate substantial wastewater, exhaust gases, and waste materials, increasing subsequent processing costs and further reducing overall energy efficiency. According to field surveys, the enterprise's current production processes have been in use for many years without timely integration of the latest technological advances. In key production stages such as clarification, filtration, and evaporation, the enterprise still relies on traditional methods rather than adopting more efficient and environmentally friendly modern technologies, which can result in high energy consumption and low production efficiency.

Table 10. Analysis of negative product costs by cost type (Unit: Yuan)

	Extraction Center	**Clarification Center**	**Crystallization Center**	**Packaging Center**	**Total**
Negative Cost	36,734,703.54	31,038,639.20	11,674,650.42	445,214.95	79,893,208.11
Percentage	45.98%	38.85%	14.61%	0.56%	100.00%

4.3 Comparison Analysis of MFCA and Traditional Accounting Methods

Comparing the results of MFCA with traditional accounting methods before and after implementation, D Sugar Industry's current unit sugar production cost calculated by traditional accounting methods is approximately 6,136.79 yuan per ton, whereas MFCA calculates a unit sugar production cost of about 4,466.76 yuan per ton. The adoption of MFCA significantly lowers the unit production cost compared to traditional accounting methods, indicating that MFCA results more closely align with actual production costs. This provides a more scientific basis for product pricing and helps the enterprise better understand its cost structure. Additionally, unlike traditional cost accounting, MFCA encompasses not only financial costs but also material flows during production, such as raw materials and energy. This comprehensive accounting perspective assists the enterprise in scrutinizing production activities from a broader viewpoint, identifying potential environmental impacts and improvement opportunities. The most important thing is that the production activities in the sugar industry are different from many other industries, usually closely related to the harvest season of crops, and belong to seasonal production. MFCA can help identify the impact of seasonal changes on environmental costs. Compared with other environmental accounting methods, MFCA is more suitable for enterprises that want to optimize internal processes, reduce costs, and minimize environmental footprints. It can help the sugar industry identify and prioritize the most significant sources of environmental costs, thereby making more sustainable decisions.

5 Conclusions and Recommendations

5.1 Conclusions

This paper conducted an environmental cost accounting study of D Sugar Industry based on MFCA using methods such as literature review and on-site investigation. Firstly, guided by the theory of environmental costs, it summarized the current status of cost accounting in D Sugar Industry and analyzed a series of issues in environmental cost accounting for the enterprise. Secondly, based on the principles of MFCA and considering the actual situation of D Sugar Industry, it constructed an environmental cost accounting system. By calculating the environmental costs of D Sugar Industry in 2023 and analyzing the results, the study finds: Firstly, sugar production processes entail significant resource losses, imposing economic costs on both internal operations and external environments. Secondly, material loss costs and energy loss costs constitute a considerable proportion of total resource losses. Sugar manufacturers can enhance material management practices and anticipate the use of lime milk and chemical reagents, exploring alternative materials or methods. Moreover, industrial sugar production generates substantial wastewater containing high concentrations of organic matter and sugars, severely polluting water environments. Companies should strengthen water resource management and emphasize the degree of wastewater recycling. Thirdly, compared to traditional cost accounting methods, MFCA offers certain advantages in environmental cost accounting.

In conclusion, strategies for controlling environmental costs in the sugar industry are proposed focusing on material cost control, optimization of clarification processes to reduce energy costs, and strengthening water resource management, providing insights for similar enterprises.

5.2 Recommendations

(1) Reduce Pressing Material Losses

In terms of material cost control, it is recommended that the sugar industry adopt more efficient pressing techniques and modern equipment to minimize material losses. For instance, high-pressure continuous presses can increase sugar beet juice extraction rates, reducing residual sugar content in waste materials and thus minimizing raw material waste. Regular maintenance and equipment upgrades are crucial to maintaining optimal operational conditions and reducing losses. Additionally, leveraging advanced processing technologies to improve raw material utilization, such as precise batching systems to reduce overuse and rigorous quality inspections to minimize production defects and rework costs, can enhance final product compliance. It is advisable to utilize digital tools for real-time monitoring and data analysis during pressing processes, monitoring metrics such as raw material input, juice extraction rates, and sugar content in waste materials, identifying high-loss areas for optimization measures.

(2) Optimize Clarification Processes and Reduce Energy Costs

Addressing the high energy costs associated with clarification centers, the paper suggests using efficient clarifying and filtering agents to reduce reliance on heated limestone and consequently lower energy consumption. Furthermore, improving heating methods by introducing more efficient heating equipment, considering modern technologies like steam jet heating to replace traditional heating methods, can enhance thermal energy utilization efficiency. Exploring energy recovery methods, such as installing heat exchangers to capture waste heat from production processes, can reduce dependence on fresh energy sources. Lastly, encouraging the sugar industry to explore and adopt new clarification technologies such as membrane separation and ozone treatments, which may offer lower energy consumption, can potentially reduce negative product rates in clarification centers and minimize resource losses.

(3) Strengthen Water Resource Management

To enhance water resource recycling in the sugar industry, companies can establish rainwater collection reservoirs and purification systems to gather rainwater from rooftops and ground surfaces. After suitable treatment, this water can be used for factory greening, road cleaning, or as supplementary production water, effectively utilizing non-traditional water resources. Additionally, redesigning cooling water circulation system designs, such as adopting closed-loop cooling systems, can significantly reduce water evaporation losses. Installing efficient heat exchangers and regularly cleaning scale deposits can enhance cooling efficiency, thereby reducing water resource consumption. Utilizing drip filtration equipment nozzles to increase pressure and accelerate the spraying of inorganic salt nutrient solutions can expedite the decomposition of organic pollutants dissolved in water, enhancing wastewater treatment capacity and reducing wastewater discharge volumes and external environmental damage costs. Finally, establishing a series of wastewater reuse systems and employing advanced treatment technologies like reverse osmosis, ultrafiltration, and electrodialysis to further purify treated wastewater to meet or approach fresh water standards, for reuse in production processes such as cooling, cleaning, and toilet flushing, facilitates water resource recycling.

Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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