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Scientific Platform

Application of material flow cost accounting to achieve environmental sustainability in small-scale soybean oil production in South Africa

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Abstract: *Purpose:* This study investigates the effectiveness of Material Flow Cost Accounting (MFCA) as a tool for enhancing resource efficiency and environmental sustainability in small-scale soybean oil production in South Africa. The main objective is to analyze the impact of MFCA on waste reduction and economic performance within the production process.

Methodology: A case study approach was adopted, focusing on the implementation of ISO 14051 in a small-scale soybean oil production setting. Data were collected through direct observation over three months, capturing cost information, inputs, and outputs across the various production stages.

Results: The findings indicate that a significant portion of waste generated during soybean oil production can be reused as by-products in other processes. The application of MFCA led to notable cost savings and promoted environmental sustainability. Specifically, the technique resulted in total savings of 6,083.05 Rands, with 196.97 Rands saved in dehulling, 4,609.08 Rands in drying, 350 Rands in oil extraction, and 927 Rands in filtration. The study also highlights the potential for revenue generation and improved resource utilization through waste minimization and reuse.

Theoretical Contribution: This research contributes to the literature by demonstrating the value of MFCA in agri-food production, emphasizing its role in reducing waste, costs, and energy use while supporting sustainability objectives.

Practical Implications: The results provide actionable recommendations for industry practitioners,

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policymakers, and scholars, advocating for the adoption of MFCA in soybean oil and similar production processes to achieve sustainable development goals.

Keywords: material flow cost accounting, environmental sustainability, waste reduction, waste diversion, soybean oil production, resource efficiency, South Africa

Sustainable Development Goals (SDGs): SDG 2: Zero Hunger; **SDG 6:** Clean Water and Sanitation; **SDG 7:** Affordable and Clean Energy; **SDG 9:** Industry, Innovation and Infrastructure; **SDG 12:** Responsible Consumption and Production; **SDG 13:** Climate Action; **SDG 15:** Life on Land; **SDG 17:** Partnerships for the Goals

1. Introduction

Significant amounts of waste materials are usually produced throughout manufacturing processes, and there is growing awareness of the cost implications. As a result, two key questions arise: How do we prevent such an enormous quantity of waste and find possible savings? What economic and environmental benefits might be derived from waste materials? The answer appears to be Material flow cost accounting (MFCA), a management technique that helps industrial organizations improve their material efficiency. According to Schmidt and Nakajima (2013), MFCA evaluates material losses in production processes in monetary terms and emphasizes the economic and environmental benefits. According to the International Organization for Standardization 14052 (2017), MFCA fundamentally tracks the stock and movement of materials in a production process, quantifies these flows in physical units (e.g., volume and mass), and assesses the costs associated with material flows and energy use. ISO 14052 (2017) further stated that MFCA applies to any organization that utilises materials and energy, irrespective of its products or services, structure, size, location, or current management and accounting systems.

2. Literature review

This section addresses the main concepts covered in the study. These are material flow cost accounting, soybean oil production, and environmental sustainability.

2.1. Material flow cost accounting

According to ISO 14051 (2014), MFCA is a management tool that improves the transparency of material flow, which is essential for successful problem-solving and improvement. In today's world, organizations pay much attention to the environmental impact of their activities. Government and regulatory bodies heavily penalize those whose activities negatively impact the environment. As a result, organizations seek appropriate tools and techniques that may link environmental concerns with economic considerations.

The MFCA technique has been successfully applied in various industries worldwide to assist firms in discovering inefficiencies, reducing waste, and achieving economic and environmental benefits. Some of these industries include the forestry industry (Papaspyroupolos, Karamanolis, Sokos & Birtsas, 2016), bottled mineral water industry (Tran & Herzig, 2022), paper and pulp industry (Doorasamy, 2016), trigger coil production (Kasemset, Boonmee & Khuntaporn, 2016), and textile industry (Kasemset, Chernsupornchai, and Pala-ud, 2015), to name a few, with positive results. However, the use of MFCA in the soybean oil production process has received little attention in the literature, presumably because applying the MFCA technique requires some technicalities that some researchers might consider to be cumbersome.

2.2. Soybean oil production

Soybean oil production is a major contributor to the agri-food industry, with cost efficiency and sustainability being its main objectives, and it also contributes substantially to economic growth (Joel, Doorasamy & Akinola, 2024). However, despite this positive economic contribution, the production process could also have negative ecological impacts, resulting in serious environmental consequences. There are two primary soybean oil extraction methods: mechanical and solvent (Ramanujan, 2006). The latter method is often preferred because of its shorter extraction time, large production capacity and high percentage of oil recovery (Geow, Tan, Yeap & Chin, 2021); however, serious health and environmental concerns have been raised severally about this method because of the use of hexane, the use of which this method entails (Cheng, 2017; Martinho, Matos, Gani, Sarup & Youngreen, 2008; Patrachari, 2006). According to these studies, hexane is hazardous, very combustible, causes irritation, and has been linked to nervous system damage in those exposed to substantial quantities of it. These concerns have sparked increased interest in the mechanical extraction method.

The mechanical extraction method entails applying pressure to extract oil mechanically from an oilseed. This method is often preferred because of the minimal or no refining it entails and the high quality of oil obtained. Although the yield is smaller compared to the solvent extraction method, the oil recovered from soybeans through mechanical pressing is of higher quality, protein-rich, and non-contaminated (Usenu, Aremu, Tijani, Idowu, & Alade, 2021; Islas-Rubio & Higuera-Ciapara, 2002; Bargale *et al.,* 2000). Thus, it is a matter of *quantity* versus *quality*. Cheng (2017) reported that the mechanical expelling process had the least environmental impact out of all the examined soybean oil extraction methods, and companies worldwide are all tending towards ensuring the production of environmentally-friendly and sustainable products. According to Faleh *et al.* (2019), producing such products requires minimal energy and quantity of raw materials, does not require toxic substances, and uses recyclable packaging, among others. It must be noted that only mechanically-extracted soybean meal is used in organic poultry diets. Kondo and Nakamura (2005) define waste management and recycling procedures as organizations' efforts to improve eco-efficiency by comparing inputs and outputs during the operational process. According to Schmidt and Nakajima (2013), organizations must ask themselves some pertinent questions about the waste materials generated from their manufacturing processes. According to them, these questions include: Is the disposal of negative materials (waste) expensive? Can one consequently save costs by reducing the quantity of negative materials? Or are the negative materials valuable enough to be recycled?

This study's dependent variable is environmental sustainability, while material flow cost accounting (MFCA) is the independent variable. The variables used to proxy the dependent variable include *electricity usage, water usage, air pollution, and waste diversion*. This study aims to reduce electricity usage, water usage, air pollution and waste generation while ensuring that any waste generated is either reused or recycled. This study's soybean oil production process entailed eight steps, and the dependent variables will be discussed as they relate to and contribute to environmental sustainability. All relevant data on each variable and for each step of the production process will be provided.

2.3. Environmental sustainability

Companies are developing more environmentally-friendly products and are concerned with reducing environmental impacts through environmental management measures. Waste reduction is a significant strategy for reducing the negative environmental impact of production (Dekamin & Barmaki, 2018). Organizations need access to tools that will enable them to keep track of all inputs and outputs of their operations to support eco-efficient decisions that will simultaneously improve their environmental and economic performance (Christ & Burritt, 2015). The authors further stated that all materials acquired by an organization must result in either a product or non-product (waste). A major challenge, therefore, seems to be promoting environmental management systems that target a low-carbon economy (Nakajima, Kimura & Wagner, 2013). By adopting MFCA in their operations, managers can manage the waste, reduce it, recycle it, or sell it as input in other production processes (Wan, Ng, Ng & Tan, 2015).

2.4. Theoretical framework

The two theories underpinning this study, the Circular Economy (CE) Theory and the Ecological Modernization Theory (EMT), are presented below.

2.4.1. Circular economic theory

According to the circular economy theory, products should be developed with the end in mind so that all resources can be recycled appropriately into the environment or utilized to produce new products (Kristensen & Mosgaard, 2020). This philosophy promotes the use of renewable energy and safe materials. It also promotes sustainable production and resource conservation. The theory focuses on resource efficiency, waste minimization, and material reuse. Implementing circular economy principles and practices is crucial because it enables firms to convert objects that have reached the end of their life cycles into resources to create new products (Barros, Salvador, do Prado, de Francisco, & Piekarski, 2021). The circular economy theory was deemed relevant to this study since it is consistent with the MFCA's goal of identifying and quantifying material losses in monetary terms to achieve sustainability. The theory was also considered relevant to the current study since, like MFCA, it promotes waste minimization and resource optimization.

2.4.2. Ecological modernization theory

Joseph Huber, a German professor, proposed the EMT, an environmental sociology theory, in the 1980s. According to this theory, moving toward environmentalism benefits the economy. It promotes the efficient use of environmental media (including air, soil, ecosystems, and water) and natural resources. Proponents of this theory claim that ecology and economy can be effectively merged. According to Adua, Clark, and Jorgenson (2022), the theory facilitates several intermediate processes, such as implementing environmental protection regulations, green production and consumption practices, and investment in efficiency development. The EMT argues that there should be a win-win relationship between economic growth and the environment and that environmental improvements will lead to increased economic development (Langhelle, 2000). The EMT mainly emphasizes integrating environmental sustainability into an organization's economic and political frameworks in modern cultures in acceptable ways, frequently through institutional and technological advancement (Spaargaren, 2000). Environmental valuation should be factored into economic decisions, just as economic valuation should be factored into ecological impact, and firms should increasingly prioritize environmental sustainability in their operations (York, Rosa & Dietz, 2010). One major criticism of the EMT is that it focuses on advanced nations while disregarding the impact of economic inequality and globalization on developing and underdeveloped countries. Another criticism of the EMT is that firms may engage in superficial environmental action, making them appear sustainable while making no significant improvements. Some critics of this theory contend that it implicitly assumes that promoting environmental sustainability and improvements is economically feasible, which is not always the reality (Fisher & Freudenburg, 2001). The EMT was considered relevant to this study because SMEs want to achieve economic development and should understand that economic development and environmental sustainability are not mutually exclusive but may co-exist and be strengthened.

2.5. Empirical review of literature

Fakoya and van der Poll (2013) conducted case study research to assess the impact of ERP and MFCA strategies on waste management in a South African brewery. Data were collected via interviews and questionnaires. The study discovered that ERP and MFCA methodologies assisted in identifying cost inefficiencies associated with material losses, such as underutilized raw materials and by-products. The transparency provided by MFCA enabled targeted improvements in cost allocation and waste management. Furthermore, Wohlgemuth and Lütje (2018) used a case study from the gastronomy industry to demonstrate the effectiveness of MFCA in assessing industrial organic waste streams for energy use. The study discovered that employing this technique regularly could result in environmental and economic benefits for the business and aid economic development. Also, Papaspyropoulos, Karamanolis, Sokos, and Birtsas (2016) investigated the impact of utilizing MFCA in forest management techniques in Greece. The study's findings revealed that by accounting for both negative (undesired or non-productive) and positive outputs, forestry organizations may better understand their operational inefficiencies, environmental impacts, and impact on the natural environment. Nordin (2017) examined the application of MFCA in a traditional cottage industry, specifically on batik making in Malaysia. The study's findings revealed that the application of MFCA in batik-making reduced environmental pollution and can be utilised to achieve increased productivity and decrease production costs. Mahmoudi, Jodeiri, and Fatehifar (2017) also used the case study approach to apply the MFCA technique to an Iranian wastewater treatment facility. The study discovered that by applying the technique, process improvement was used to minimize the amount of toxic waste produced, resulting in a significant reduction in the release of these compounds into the environment. Chompu-inwai, Jaimjit, and Premsuriyanunt (2014) employed the MFCA and designed experiments (DOE) techniques at a wood product manufacturing company. The study focused on three factors, and an analysis of variance (ANOVA) was performed. The experiment yielded a 15% reduction in wood material losses throughout the cutting process as a percentage of total wood materials used. The techniques contributed to higher product quality, cost savings, increased competitiveness, and reduced the negative environmental impact of the company's manufacturing process.

These studies all demonstrated that applying the MFCA technique promoted environmental sustainability. However, it remains to be seen if applying the MFCA technique in soybean oil production will yield similar results.

Soybean oil production involves multiple processes, each of which generates waste. In this study, the soybean oil production process entailed eight steps (processes), namely (1) seed cleaning, (2) washing and boiling, (3) dehulling, (4) cracking, (5) drying, (6) oil extraction, (7) filtration, (8) packaging.

3. Methodology

This study adopted a case study approach. A case study is not designed to investigate a complete organization but rather to focus on a specific issue, feature, or unit of analysis (Noor, 2008). According to Sekaran and Bougie (2013), a case study gathers information about a specific event or activity, such as a particular business unit or organization. This study centered on soybean oil production, which falls under the business unit category. The approach was deemed appropriate since it provided a clear view of the production process by evaluating it in a real-world setting.

This study employed a qualitative case study approach to systematically examine the application of Material Flow Cost Accounting (MFCA) in a small-scale soybean oil production facility in South Africa. The case study design was chosen to provide an in-depth understanding of the production process, waste generation, and the economic and environmental impacts of MFCA implementation within a real-world context.

3.1. Data collection

Primary data were collected through direct observation of all stages of the soybean oil production process over a three-month period. The researchers documented inputs (raw materials, water, energy), outputs (soybean oil, by-products), and waste generated at each step. Quantitative data on material and energy flows, as well as associated costs, were recorded for each of the eight production stages: seed cleaning, washing and boiling, dehulling, cracking, drying, oil extraction, filtration, and packaging.

3.2. MFCA implementation

The MFCA methodology was applied in accordance with ISO 14051 guidelines, which involve tracking and quantifying material flows in both physical and monetary terms. For each production stage, the mass balance of inputs and outputs was established, and costs were allocated to both products and material losses (waste). This enabled the identification of inefficiencies, waste minimization opportunities, and potential for by-product utilization.

3.3. Data analysis

The collected data were analyzed to determine the proportion of materials converted into final products versus waste and to calculate the cost savings and environmental benefits resulting from MFCA implementation. The analysis focused on identifying stages with the highest material losses and evaluating the potential for waste reduction and resource efficiency improvements.

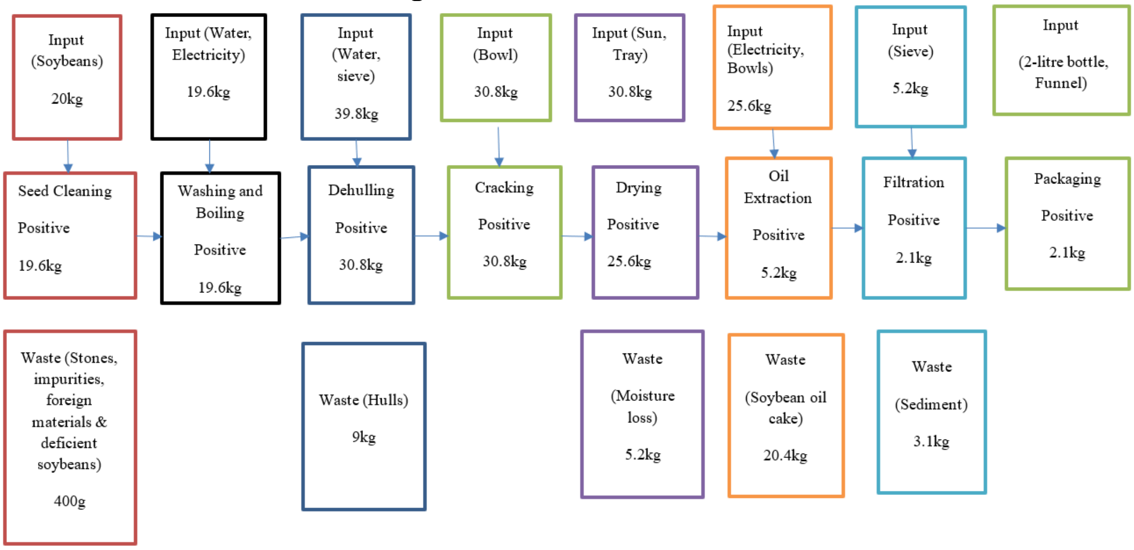
3.4. Ethical considerations

All observations and data collection were conducted with the consent of the facility operators, and no personal or sensitive information was gathered. The study did not involve human participants, and thus, informed consent was not required.

4. Results

The material flow model in Figure 1 illustrates that only five of the eight processes produced waste: seed cleaning, dehulling, drying, oil extraction, and filtration. Furthermore, as illustrated in Figure 1, approximately 20kg of soybeans were required to produce 2kg of soybean oil. The seemingly low oil recovery is consistent with Carlson and Garrett's (2018) submission, which claimed that, while soybean is categorized as an oil crop, it contains more protein (40%) than oil (20%). It should be emphasized that this study did not cover the refining process. Also, in step 3, the soybeans swelled up and became more than double the original quantity after boiling due to water retention. This swelling explains the 39.8 kg input stated in the third process.

Figure 1: Material flow model

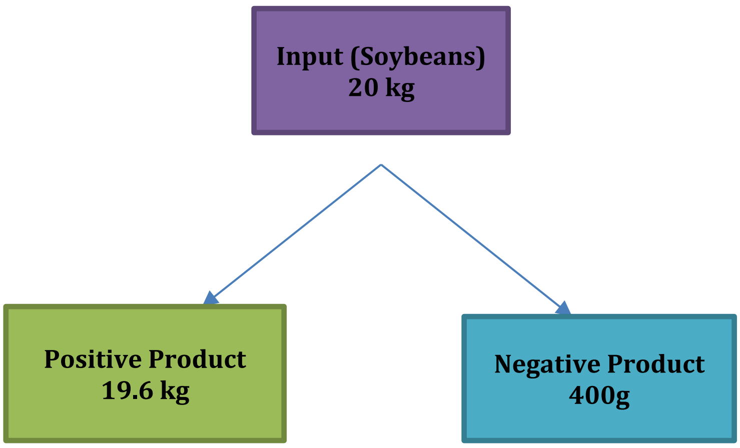


Source: Authors' computation (2025)

Step 1: Seed Cleaning

This step entailed careful removal of stones, impurities, and foreign materials. Soybeans were bought in a local market in Johannesburg, South Africa. The initial step was carefully removing the stones, contaminants, and extraneous objects. After threshing, soybeans get contaminated with dirt, soil, insects, plant waste, broken kernels, and other contaminants, which make drying more difficult and time-consuming (Islas-Rubio & Higuera-Ciapara, 2002). Seed cleaning is important because it ensures that only wholly cleaned soybeans are processed. The seed cleaning was manually done and did not require electricity or water use. 20 kg of soybeans were measured, of which 400g of impurities were taken out. The remaining soybeans were then weighed, which was 19.6kg. All the impurities and foreign materials were properly disposed of as they could not be used further.

Figure 2: Data on seed cleaning (20 kg of soybeans)



Source: Authors' computation (2025)

Step 2: Washing and Boiling

This step entailed thoroughly washing the soybeans for about 25 minutes. Two variables came into play in this step: water and electricity usage. Water was used to wash the soybeans, while electricity was used to boil them. Steam was also generated during the boiling process; however, this could not be quantified. For the 19.6 kg of soybeans, about 8 litres of water were used for repeatedly washing and boiling the soybeans, and 1 kWh was used for the 25-minute boiling period. The soybeans were repeatedly washed until they were clean, which was when the water was no longer dirty and cloudy but very clear. The boiling process removes any enzymes contributing to the soybeans' deterioration and prepares them for oil extraction. Boiling increases extracted soybean oil's quality and shelf life (Tulashie, Kotoka, Appiah, Awuah, & Baiden, 2018).

Figure 3: Boiling the soybeans

Source: Authors' compilation (2025)

Step 3: Dehulling

This step entailed the removal of hulls by severely squeezing the beans, which had become softened by the previous step, and passing the floating hulls through a strainer or sieve. This process was repeated ten times until the hulls were almost removed entirely (about 95%) from the beans. The dehulling process required water for the efficient removal of the soybean hulls. This study noted that the soybeans swelled up due to water absorption and more than doubled the initial quantity after boiling. According to Demarco and Gibon (2020), the dehulling procedure is crucial for achieving a high protein level, reducing the final fibre of soybean meal, and improving oil extraction efficiency.

Figure 4: Soybean Hulls

Source: Authors' compilation (2025)

Step 4: Cracking

This step entailed cracking the soybeans into smaller pieces, crucial to creating pieces of the appropriate size to provide the best flakes for oil extraction. This process was manually undertaken, and none of the variables came into play.

Figure 5: Cracked soybeans

Source: Authors' compilation (2025)

Step 5: Drying

In this study, the soybeans were sun-dried continuously for about a week until completely dried. This step also did not involve any of the variables.

Step 6: Oil Extraction

The soybean oil extracting machine was pre-heated for about ten minutes, after which the soybeans were poured into the hopper and the extraction began. It took about ten minutes to extract oil from one kilogram of soybeans. Three variables were involved here: electricity usage, air pollution, and waste diversion. It took about three hours and thirty-one minutes to extract oil from 25.6 kg of soybeans.

Step 7: Filtration

The extracted oil was collected in a big stainless container, and a big filter was placed on the stainless container to filter the oil coming directly from the machine because the oil quality was quite impure as it contained some sediments. This step ensured clean oil was obtained with minimal sediments. The sediments were the solid waste generated during the filtration process.

Figure 6: Filtration

Source: Authors' compilation (2025)

Step 8: Packaging

The 2.1 kg of filtered and unrefined soybean oil (the end product of the initial 20 kg input soybeans) was promptly bottled in an airtight container to prevent rapid oxidation.

Identifying Waste Minimisation and Reuse Opportunities

This step entails identifying the root cause of waste generation in each production process and determining different minimizing, reusing, and recycling opportunities, where applicable.

5.3.1 Step 1: Seed Cleaning – As earlier stated, all the foreign materials and impurities obtained from cleaning the soybeans were properly disposed of, as they could not be put to any further use.

5.3.2 Step 2: Washing and Boiling - The soybeans contained a lot of dust and dirt; therefore, it was repeatedly washed until the soybeans became completely clean. The water used for washing the soybeans could be used to water flowers and plants rather than being poured down the drain or directly discharged into the environment, which is what is typically done, thereby causing environmental pollution. According to Ropiudin and Syska (2023), the water obtained from this step could be filtered and reused to sanitize the production room. In bigger soybean oil manufacturing companies, pipes could be connected to nearby farmlands for irrigation. Also, the boiling water of the soybeans could be cooled down and transferred to the following process, dehulling the soybeans. Doing this would result in water and cost savings while promoting environmental sustainability. This study used about 8 litres of water to wash and boil the 19.6kg of soybeans. Rather than pouring the water down the drain after washing and boiling, it could be collected in a bucket, cooled down, and reused to dehull the soybeans in the succeeding step.

Another step that could be taken to ensure water conservation and environmental sustainability in both the second and third processes is to collect rainwater in clean containers for use rather than relying solely on freshwater resources. Rainwater is free and pure and could significantly minimize the environmental impact of the soybean oil production process. Furthermore, to ensure reduced electricity usage and energy conservation, soybean oil manufacturing companies should consider opting for renewable energy sources, like solar energy. Doing this would promote environmental sustainability.

5.3.3 Step 3: Dehulling – The use of water in the dehulling process (where the most significant quantity of water was used) could be reduced by reusing the water from the previous step (washing and boiling) to reduce water usage. The dehulling step aims to ensure the removal of the soybean hulls; therefore, the same water could be used repeatedly instead of using fresh water for each washing attempt. Doing this results in reduced water usage and also cost savings. For instance, as earlier noted in this study, the soybeans more than doubled in size after boiling, from 19.6kg to 39.8kg. The dehulling process should have required about 20 litres of water for the 20kg batch, but going by the suggested step would result in the dehulling process using only about 5 litres of water for the final rinsing of the soybeans after completing the dehulling. All the water from this process could be collected in a big container and used to water plants and flowers.

Waste Diversion of the Soybean Hulls

The waste generated in this step was the *soybean hulls*. According to Liu and Li (2017), soybean hulls constitute about 5% of the soybean; therefore, they are the most significant by-product generated during soybean oil processing. According to several studies, these soybean hulls are fibrous and could be used as non-conventional animal and aquatic feed resources (Chellapandian, 2019; Liu & Li, 2017; Shuaib *et al.,* 2023). According to Esonu (1998), incorporating soybean hulls in moderate to high proportions into maize-based finisher diets increases the feeding value of maize by 74–80%. Including soybean hulls in animal feeds is environmentally friendly and could partially substitute corn and soybean meal in non-ruminant diets (Shuaib *et al.,* 2023). Chellapandian (2019) found that soybean hulls had sufficient nutritious content, high dry matter intake, and easily digested nutrients to meet the needs of adult sheep.

5.3.3.2 Animals that Benefit from Soybean Hulls

The following are some animals established in the literature to benefit from including soybean hulls in their diets. These include (a) Dairy cows, (b) Sheep, (c) Goats, (d) Poultry birds, (e) Dogs, (f) Cats (g) Fish.

5.3.4 Step 4: Cracking – The cracking process in the soybean oil production process usually involves electricity usage. Soybeans are cracked to get appropriate bean sizes for flaking before oil extraction. However, the cracking process was manually done in this study, resulting in energy and cost conservation.

5.3.5 Step 5: Drying – The soybeans were sun-dried rather than using an electrical dryer. The sun-drying method resulted in energy and cost conservation. 30.8kg of soybeans were sun-dried continuously, and after one week to two weeks, the quantity of soybeans had reduced to 25.6kg due to moisture loss. In the literature, some studies, like Cheng and Rosentrater (2017), employed steam as the heating agent in the drying process. However, the current study opted for sun-drying because it has cost and environmentally friendly advantages. Also, sun-drying is a free and renewable source of energy. Care was taken to ensure the soybeans were not exposed to rain, birds, dust, dirt, or other contaminants. Small and medium-scale soybean oil manufacturing companies should consider the sun-drying method as it is cost and environmentally friendly. Medium-scale and large-scale manufacturing companies could also benefit from this method by drying the soybeans in batches in an elevated position. It must be ensured that the soybeans are protected from birds and environmental pollutants.

Step 6: Oil Extraction - According to Salem *et al.* (2022), various pollutants are produced during soybean oil production, which might cause environmental hazards if not adequately managed and disposed of. Electricity was the primary energy source in the oil extraction process. About 5.09 kWh of electricity was consumed during the process. However, it has been established in the literature that electricity has detrimental effects on the environment, including contamination of the air, water, and soil, resulting in environmental degradation and pollution (Farghali *et al.,* 2023; Bella *et al.,* 2014; Elum & Momodu, 2017; Stamatiou, 2023). Therefore, the oil extraction method with the least electricity usage and environmental impact in environmental sustainability should be opted for. About 20.4 kg of the negative product was generated from the 25.6kg of soybeans imputed into the soybean oil extracting machine during the oil extraction process. This waste, commonly called *soybean oil cake* or *meal,* remains after extracting oil from soybeans. According to Zamindar *et al. (2017), soybean oil cake consists of several chemical constituents: crude fat, ash, moisture, crude protein, and* fiber. Soybean cake is also a promising ingredient for bread and other baked products (Mashanova *et al.,* 2024; Jideani, 2011).

The most predominant demand for soybean oil cake is from the animal feed industry. According to Vichare and Morya (2024), edible oil cakes are generated from oil-bearing seeds such as soybeans, groundnuts, rapeseeds, sunflowers, safflowers, coconuts, linseeds, and cottonseeds, and they are used for animal feed or human consumption. As of 2015, domestic soybean oil cake production accounted for only 10% of total domestic soybean oil cake consumption, with over 90% imported from Argentina (Dlamini, 2015). While maize is the primary energy source in pig diets, soybean oil cake is the primary protein source; it is also rich in amino acids, such as tryptophan and lysine (Cronje, 2019). In some places, the soybean oil cake is more expensive than the soybean oil. Also, soybean oil cake is traded at higher prices than oil cake from other oilseeds, like sunflower (Manthata, 2018).

Figure 7: Soybean Oil Cake

Source: Authors' compilation (2025)

Animals that Benefit from Soybean Oil Cake

The following are some animals that benefit from including soybean oil cake in their diets. These include (a) Cattle, (b) Swine, (c) Poultry, (d) Turkeys, (e) Hogs, (f) Fish, (g) Chickens, (h) Pigs.

5.3.7 Step 7: Filtration – As previously stated, the soybean oil was filtered after the oil extraction. The solid waste obtained from the filtration process is called *sediment*. Rather than discarding the solid waste into the environment, thereby causing blockages and potential environmental hazards, this waste was carefully separated from the soybean oil and could be used to create *lecithin,* an essential ingredient found in many cookies, biscuits, chocolate bars, and sweet treats, like *Oreos*. Lecithin is widely used in cosmetic, pharmaceutical and food industries (Gutiérrez-Méndez, Chavez-Garay & Leal-Ramos, 2022; Wu & Wang, 2003, Machado, de Assis, Machado & de Souza-Soares, 2014; Akit, Sazili, Ismail, Atan, Shazali & Loh, 2016). Soy lecithin is a flavour protector, antioxidant, and food lubricant, and also extends the shelf life of products (Wilson & David, 2017; Pan, Tikekar & Nitin, 2013; Gaudino, Ghazani, Clark, Marangoni & Acevedo, 2019). The soy lecithin is then sold to cookies, biscuits, and sweet treats manufacturing companies, like Cadbury and Nestle.

This results in economic benefits to the soybean oil production companies and also promotes environmental sustainability. According to Steffen (2021), economic prosperity must harmoniously co-exist with environmental sustainability. After filtering the extracted 5.2kg of soybean oil, the study obtained 2.1kg of pure soybean oil and 3.1kg of sediment/solid waste. The current price of soy lecithin in South Africa is R299/kg. Therefore, a total sum of about R927 could be saved if the solid waste is processed into lecithin and sold to buyers.

Table 1: Waste diversion from the filtration process

	20 kg		50 kg		100 kg	
Soybean oil sediments	3.1kg	927 Rands	10.62kg	3176.65 Rands	22.63kg	6762.88 Rands

Source: Authors' computation (2025)

Figure 8: A Variety of Oreo Snacks

Source: LeClair for the Business Insider, August 5, 2020

In South Africa, *soy lecithin* is found in many snacks and powdered milk, like the Tiffany biscuit brand, Oreos snacks and cookies, and Nestle powder milk.

Figure 9: Tiffany biscuit and Nestle powder milk

Source: Authors' compilation (2025)

Both products in Figure 9 above have soy lecithin as one of their ingredients.

Step 8: Packaging – The extracted soybean oil was promptly transferred into a bottle and tightly covered to prevent oxidation. The packaging process did not involve water or electricity usage. According to List, Wang and Shukla (2020), oils can be damaged during storage, resulting in a loss in quality and yield. To maximize the shelf life of vegetable oils, like soybean oil, they must be promptly stored in dark glass bottles. Also, to prevent oxidation, the bottles must not be partially complete, but the oil must fill up the bottles, and the bottle caps must be secured tightly. The oil must be stored in a dark, cool, dry place away from direct sunlight. Opio and Photchanachai (2018) reported that a modified storage environment decreases the rate of oil oxidation.

Figure 10: Framework for the study

Source: Authors' compilation (2025)

According to Dhahi and Abdullah (2023), to achieve environmental sustainability, MFCA provides information that focuses on reducing the amount of materials and energy consumed in the production process, reducing the volume of waste and emissions that impact the environment, and thus protecting the environment from pollution. This study has succeeded in achieving this objective.

Table 2: Economic benefits of applying MFCA to achieve environmental sustainability

Quantity centres	Without the MFCA application (Rands)	With the MFCA application (Rands)	Cost savings (Rands)
Seed cleaning	700	700	-
Washing & boiling	755.03	755.03	-
Dehulling			
(Water usage)	115.96	28.99	86.97
(Waste diversion)	-	110	110
Cracking	1,228	1,228	
Drying			
(Non-electricity usage)	-	4609.08	4609.08
Oil extraction			
(Waste diversion)	-	350	350
Filtration			
(Waste diversion)	-	927	927
Packaging	168	168	-
Total Cost Savings			6, 083.05

Source: Authors' computation (2025)

Table 2 shows the total cost savings achieved by reducing, reusing, and recycling waste materials or negative products in the soybean oil production process. The sum of 6,083.05 Rands was saved by applying the MFCA technique to achieve environmental sustainability. A total of 196.97 Rands was saved in the dehulling process, 4609.08 Rands was saved in the drying process, and 350 Rands was saved in the oil extraction process, while 927 Rands was saved in the filtration process.

5. Discussion

5.1. Policy implications

By examining the impact of applying the MFCA technique on waste, cost, resources, and environmental sustainability, this study's findings contribute to the extant literature on material flow cost accounting. This study has established that not only can the technique be applied in soybean oil production, but its application could result in waste reduction, cost reduction, and promotion of environmental sustainability. Reducing the quantity of materials should positively affect the environment and result in increased revenue in the long run. This fact is of utmost importance to policymakers in the soybean oil production industry, small-scale and individual soybean oil business owners, and all relevant stakeholders. This study is the first that have been undertaken on the practical application of the MFCA technique in soybean oil production. Hence, the under-listed policy implications emanating from this study are highlighted:

a. This study provides academicians with how the MFCA technique can be applied in the soybean oil production process to achieve environmental sustainability, which could guide anyone who wishes to conduct similar research. The study can be replicated in other production processes, not just soybean oil production. The study also discussed some relevant theories, like ecological modernization and circular economy theories.

b. The study aligns with the United Nations' Sustainable Development Goals (SDGs), aimed at balancing environmental, social, and economic viewpoints across 17 goals.

5.2. Policy recommendations

As a result of this study's findings, the following recommendations are proposed:

(1) This study suggests establishing a partnership arrangement between an agency of the government and SMEs, particularly the small and medium-scale soybean oil producers. The agency is to look into the plight of the soybean oil producers and facilitate better governmental support for the SMEs.

(2) A manufacturing curriculum on the knowledge of the application of the MFCA technique should be introduced and disseminated to soybean oil production companies in South Africa, regardless of their scale of production, be it large, medium or small. Considering the significant benefits they stand to gain by implementing the MFCA technique, special efforts must be made to educate all relevant stakeholders on this helpful technique. Owners, accountants, and finance managers of soybean oil manufacturing companies should be open to learning, unlearning, and relearning everything concerning this technique.

Owing to its economic and environmental benefits, the MFCA technique should be recommended for application to all SMEs, particularly those in the soybean oil manufacturing sector, to help attach a monetary value to all waste generated and ensure waste reduction, cost reduction, and promotion of environmental sustainability.

6. Conclusion

This study demonstrates that applying MFCA in small-scale soybean oil production can significantly reduce waste, lower costs, and enhance environmental sustainability. The findings highlight the potential for MFCA to drive sustainable practices in agri-food industries, aligning with the UN Sustainable Development Goals. While the case study approach provides valuable insights, future research should expand to other contexts and employ comparative or longitudinal designs to validate and generalize the results. Policymakers and industry stakeholders are encouraged to adopt MFCA as a strategic tool for promoting resource efficiency and sustainability.

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Informed Consent

The authors declare that informed consent was not required as no human participants were involved.

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Conflicts of interest

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