GUIDE

CONDUCTING A MATERIAL FLOW COST ANALYSIS (MFCA)

cttéi

UNIVERSITÉ LAVAL | Centre de recherche en comptabilité et développement durable

INFORMATION

For more information, contact the Centre de transfert technologique en écologie industrielle (CTTÉI) or the Centre de Recherche en Comptabilité et Développement Durable (CerCeDD).

CTTEI

3005, boulevard de Tracy
Sorel-Tracy (Québec)
Canada J3R 1C2
Téléphone : 450 551-8090, poste 3516
Courriel : info@cttei.com
Site Web CTTÉI : cttei.com
Site Web Synergie Québec : synergiequebec.ca

CerCeDD

Faculty of Administrative Sciences
Pavillon Palasis-Prince, room 2630
2325 de la Terrasse Street
Quebec City, QC
Canada G1V 0A6

Telephone: (418) 656-3484
Email us: marc.journeault@fsa.ulaval.ca

CerCeDD website: https://www4.fsa.ulaval.ca/la-recherche/centres-groupes-et-laboratoires/centre-de-recherche-en-comptabilite-et-developpement-durable-cercedd/

DESIGN

Authors

Julien Beaulieu, P.Eng, M.Eng, PMP (CTTÉI)
Marc Journeault, PhD, CPA, MBA (CerCeDD, Université Laval)

Management

Claude Maheux-Picard, Eng, M.Sc.A.

Employees

Michaël Desrochers, P.Eng. and M.Env.
Quentin Bourdejeau
Audrey Morris, M.Env.

Bibliographical Reference

Centre de transfert technologique en écologie industrielle and Centre de Recherche en Comptabilité et Développement Durable (2022). Conducting a material flow cost analysis (MFCA). 40 pages.

ISBN : 978-2-9820690-5-3 (PDF)
Dépôt légal - Bibliothèque et Archives nationales du Québec, 2025
Dépôt légal - Bibliothèque et Archives Canada, 2025

TABLE OF CONTENTS

FOREWORD

Affiliated with the Cégep de Sorel-Tracy, the Centre de transfert technologique en écologie industrielle (CTTÉI) supports businesses and organisations in implementing sustainable practices, embracing clean technologies, recovering their residual materials and deploying industrial symbioses. From 2019 to 2022, it held the Chaire de recherche sur l'écologie industrielle et territoriale (CREIT) funded by the Natural Sciences and Engineering Research Council of Canada (NSERC). The aim of this Chair is to support Quebec businesses in their transition to a circular economy by providing innovative solutions to current waste management issues. The work presented in this guide, carried out in conjunction with the Centre de recherche en Comptabilité et Développement Durable (CerCeDD) at Université Laval, is a concrete outcome of this initiative.

UNIVERSITÉ LAVAL | Centre de recherche en comptabilité et développement durable

The mission of Université Laval's Centre de recherche en Comptabilité et Développement Durable (CerCeDD) is to develop research, training and knowledge transfer activities on issues related to accounting for sustainable development, in order to enrich knowledge in this field and contribute to the improvement of practices within organizations.

The development of this guide was supported by funding from the **Québec Circular Economy Research Network (RRECQ)**. Resulting from a consortium between ÉTS, HEC Montréal, Université Laval, and Polytechnique Montréal, and financed by the Fonds de recherche du Québec, this network brings together several hundred interdisciplinary researchers from Québec, Canada, and abroad. The RRECQ aim to make available to everyone an environment conducive to the development of knowledge and innovation, both social and technological, in addition to ensuring a leadership role in the field by organizing scientific and networking activities that promote the advancement and transfer of knowledge related to circular.

INTRODUCTION

Material flow cost accounting (MFCA) aims to calculate the **"cost price" of waste**. It takes into account the obvious costs associated with waste management (e.g., waste container rental, disposal fees, fuel surcharges, etc.) as well as hidden costs (e.g., purchase of materials, energy expenses, labour costs, capital expenditures, depreciation of certain equipment, etc.). On average, the collection bill represents only 10% of the actual cost associated with waste (ADEME, 2014).

This approach, which originated in Germany and is widely used in Japan, is now the subject of **ISO 14051:2011**. Since publication of this standard, the approach has seen renewed interest in both the scientific community and industry (Christ & Burritt, 2016).

Once an MFCA analysis has been completed, managers can better appreciate the economic impacts associated with waste, and consider improvement measures such as input replacement, process modification, internal recycling or the sale of by-products. Among other things, MFCA data can be used to calculate internal rates of return (IRR) for process modifications or equipment purchases.

Collaboration between CTTÉI and CerCeDD has led to a simplification of the MFCA to make it more accessible to companies. This guide is intended to provide companies and the consultants who support them with the tools they need to carry out such an approach.

Benefits of an MFCA:

- Document direct and indirect waste-related costs
- Identify opportunities for improvement and reduce manufacturing costs
- Calculate and communicate the benefits of source reduction of waste
- Justify the implementation of reduction measures or the purchase of equipment

Did You Say "Waste"?

In Quebec, the term residual material refers to "any residue from a production, transformation or use process, any substance, material or product or, more generally, any movable property abandoned or that the holder intends to abandon" (Government of Quebec, 2017). The term waste[1] is used here as an all-encompassing term to describe any material that is not part of the composition of final products. A distinction can be made between packaging, production residues, unsold products, atmospheric losses and wastewater.

1 ISO 14051 uses the terms material loss and by-product (ISO, 2011). Other terms used are non-product or negative products.

TABLE 1: **Waste Types and Examples**

Waste			
Packaging	**Production residues**	**Unsold items**	**Atmospheric emissions and wastewater**
› Cardboard boxes › Pallets › Empty containers	› Cutting residues › Spent solvents › Iron turnings	› Obsolete stock › Non-conforming items › Returns/ cancellations	› Combustion exhaust › Washing water

Who Is This Guide for?

Who Can Perform an MFCA?

The analysis is aimed primarily at manufacturing companies. However, it can be carried out by any organization that generates residual materials — in other words, almost any organization! However, it should be emphasized that the most important residues are those generated by production activities. In fact, implementation of the MFCA is most appropriate for companies that generate significant quantities of residual materials. Companies whose sole residual material is packaging should therefore be excluded. In addition, the organization can identify one (or more) production process(es) deemed relevant for carrying out the MFCA rather than all processes (new ISO 14053:2021 standard). This selection of process(es) can be made by assessing the extent of different material losses, and by identifying processes with high unit costs.

The following table illustrates the significant components of total waste costs by sector of activity. The MFCA is most relevant when the quantity of residual materials generated is significant relative to the quantity of products sold. This is the case in the agriculture, resource extraction and manufacturing sectors.

TABLE 2: **Applicability of the MFCA Method by Business Sector**

Business Sector	Agriculture	Extraction	Construction	Manufacturing	Retail	Services
Significant components of the full cost of waste						
Raw materials	●	◐	●	●	◐	◐
Water	●	●	◐	●	◐	◐
Energy	●	●	◐	●	◐	◐
Direct labour	●	●	●	●	●	◐
Equipment	●	●	●	●	◐	◐
Waste						
Packaging	●	●	●	●	●	◐
Industrial residues	●	●	●	●	◐	○
Unsold items	●	◐	◐	●	●	○
Atmospheric losses and wastewater	●	●	◐	●	◐	◐

Legend: ● **Definitely significant** ◐ **Possibly significant** ○ **Not significant**

MFCA: BASICS

The aim of the MFCA approach is to identify and measure the real costs associated with waste. This involves adding together three types of cost: material costs, system costs and waste management costs. The following section summarizes the general principles of the approach. The various concepts are illustrated using the example of a chair manufacturing process.

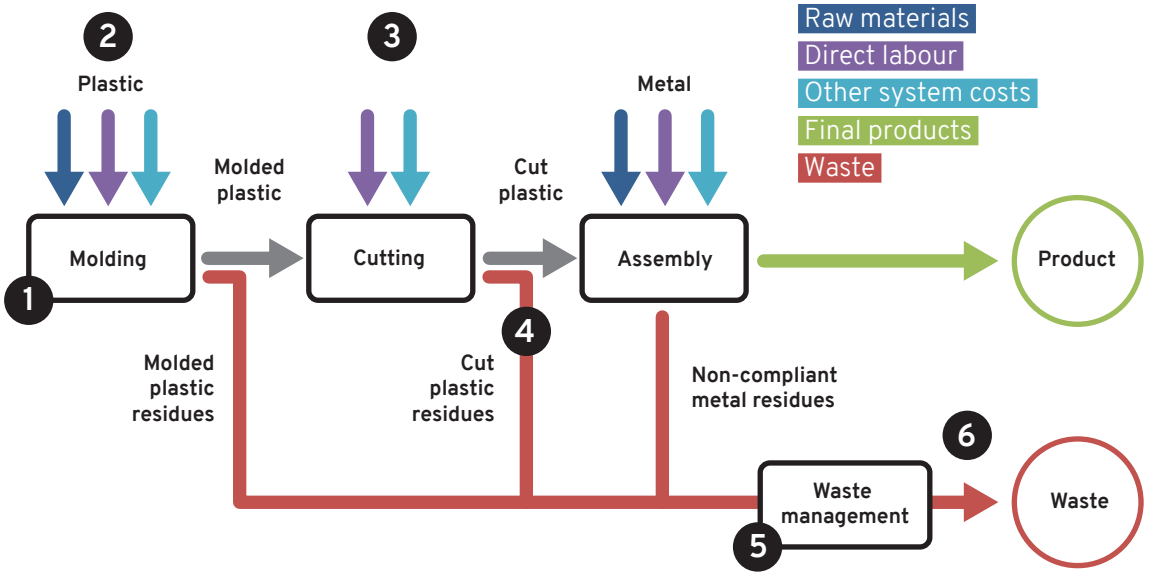


FIGURE 1: **MFCA – Basic concepts**

1 In a typical organization, materials are purchased, undergo various processing stages and then are shipped. In an MFCA, this production is divided into **quantity centre**. These blocks can describe one or more of the organization's production stages. For example, the assembly stage in Figure 1 includes both metal drilling and final chair assembly. The more quantity centres you specify in your MFCA, the more representative the information will be – however, the analysis will also be more complex and time-consuming.

2 Material costs relate to the purchase of raw materials, semi-finished products or other consumables used in production. These may be valued at historical cost or at the replacement cost of raw materials, at the discretion of the appraiser.

3 System costs include direct labour costs or Other system costs (energy, indirect labour, etc.)[2]. Frequently, these latter system costs for each quantity centre are not known, rather they are estimated for the whole manufacturing process or organization. To allocate costs between quantity centres, an appropriate **allocation criterion** should be used: machine hours, output volume, floor space occupied, etc.

2 ISO 14051 defines system costs as "costs incurred in the internal processing of material flows, with the exception of material costs, energy costs and waste management costs". It gives as examples labour costs, depreciation costs, maintenance costs and transportation costs (ISO, 2011).

4 The processes of a quantity centre transform inputs into various outputs: such as intermediate products, final products and waste. Intermediate products are used as inputs for other quantity centres, whereas final products are sold. Waste includes packaging, industrial residues, unsold/non-conforming products, atmospheric emissions and wastewater. By-products can be treated as products or waste[3]. All costs entering a quantity centre are allocated to all of its outputs. The preferred allocation criterion is mass: if a process generates 20% losses, 20% of incoming costs are allocated to waste and 80% to intermediate products. This procedure is repeated until all incoming costs have been allocated to products or waste.

5 For an organization, waste management refers to all activities dedicated to recycling or eliminating waste. These activities may be carried out internally, for example, sorting, transporting and disposing of waste. Other activities may be carried out externally, such as transporting and landfilling of waste. In an MFCA, these costs are 100% attributed to the total cost of waste.

6 The full cost of waste therefore includes the costs of waste production (i.e., a portion of material and system costs) as well as the costs of waste management.

3 Some documents on MFCA refer instead to “product” and “non-product” (ISO, 2011).

WHICH COSTS ARE RELEVANT AND SIGNIFICANT?

What Costs Should Be Included in an MFCA?

To determine whether a cost should be included in an MFCA analysis, it is important to identify its behaviour. The following table clarifies some of the descriptors normally used to differentiate between types of cost.

TABLE 3: **Cost Categories**

Type of cost	Definition	Examples
Cost behaviour		
Fixed	Does not vary according to the organization's production volume	› Fixed assets › Equipment
Variable	Changes according to the organization's production volume	› Raw materials › Manufacturing labour
Direct/Indirect		
Direct	Attributable to a particular product	› Raw materials › Manufacturing labour
Indirect	Related to the entire organization and difficult to attribute to a specific product	› Fixed assets › Administrative staff
Avoidable/Inevitable		
Avoidable	Future costs subject to change following a decision	› Raw materials › Energy
Inevitable	Costs that cannot be avoided or reduced regardless of the decision made	› Fixed assets › Equipment

In management accounting, **relevant** costs refer to the set of costs that can be affected by a given decision. It is the context that dictates whether a cost is relevant or not. In the context of an MFCA, a cost is relevant if it can be modified following the implementation of reduction, reuse or recycling measures. Relevant costs usually relate to future, variable and/or avoidable expenses. Examples include:

- Purchase of raw materials or consumables directly related to production
- Remuneration of direct labour
- Energy costs related to the operation of manufacturing equipment
- Waste management services

Conversely, **irrelevant** costs are those that are unchangeable following the implementation of reduction, reuse or recycling measures. These are costs that are already incurred, fixed or unavoidable. They include:

- Expenses incurred for the purchase of equipment or a building
- Wages for administrative employees
- Purchase of office equipment
- Energy consumption for building heating

A second criterion to consider is **significance**. The MFCA must include the most important production-related expenses but may ignore those that only marginally contribute to the overall cost of waste. Once again, context dictates whether a cost is likely to be **significant** or not. For example, a company using low-energy equipment may have **non-significant** energy costs. As a priority, the analysis should consider:

1. Purchase of materials
2. Manufacturing labour
3. Labour and services related to waste management

MFCA VARIATIONS: PRELIMINARY, TARGETED, SIMPLIFIED & DETAILED

The MFCA can be adapted to suit the information available, the resources that can be devoted to the analysis and the level of detail required. **In this guide, four variations are described: preliminary MFCA, targeted MFCA, simplified MFCA and detailed MFCA.**

The **preliminary MFCA** aims to give an order of magnitude of the full cost of waste, and does not require an in-depth analysis of the organization's manufacturing processes. For a **targeted MFCA**, we begin by looking at one of the company's problematic processes. The **simplified MFCA** provides more detailed information on the costs associated with waste, including labour costs and waste management costs, while identifying the production stages that generate this waste. Lastly, the **detailed MFCA** is based on the ISO 14051 standard and provides the most accurate assessment of waste costs.

These four MFCA variations are presented in detail in the following sections. Appendix 1 provides a "Checklist of Relevant Costs" template detailing the parameters to be evaluated for each MFCA variation, as well as suggesting potential sources of data.

It is suggested that users start with a preliminary MFCA, then refine the estimates to the desired level of detail. Another route is to start with a targeted MFCA, then progressively add analyses of other processes until the whole company has been covered. In Appendix 2, the table "Mapping the Path of an MFCA" provides a breakdown of the steps involved from a preliminary MFCA to a detailed MFCA, as well as estimating the number of hours required for each step.

TABLE 4: **Distinctions between Types of MFCA**

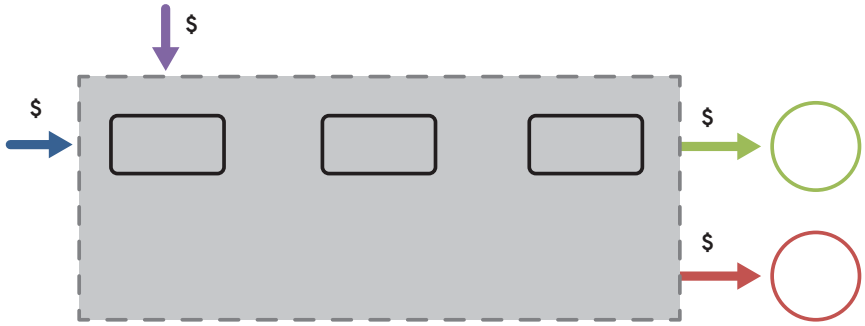
Types	Preliminary MFCA	Targeted MFCA	Simplified MFCA	Detailed MFCA
Objective	Establish an order of magnitude for the full cost of waste	Estimate the full cost of a particular residue	Identify the stages contributing to the full cost of waste	Obtain an accurate picture of the full cost of waste, in compliance with ISO 14051.
Materials	Summary	Itemized for a given cost centre	Itemized per cost centre	Itemized per cost centre
Workforce	Total direct labour	Direct labour for a given cost centre	Itemized direct labour	Direct and indirect labour
Calculate the cost of waste management	Summary	Waste management of a given cost centre	Itemized per cost centre	Itemized per cost centre
Other points analyzed			Addition of significant costs as needed	Energy and water costs Internal recycling Inventory variations Inventories, atmospheric emissions and wastewater Revenue from waste
Complexity **Usefulness**				

Several people may be involved in a MFCA. The following table lists the responsibilities of each stakeholder.

TABLE 5: **Roles and Responsibilities**

Role	Responsabilities
Analyst (internal or external)	› Leading meetings › Modeling and analysis
Management	› Supporting the project › Defining objectives › Approving reduction opportunities
Production Manager	› Providing information on production › Identifying reduction opportunities › Implementing reduction opportunities
Accounting Manager	› Providing information on costs
Production workers	› Providing information on production › Identifying reduction opportunities
IT Services	› Providing information on production

PRELIMINARY MFCA



The purpose of the preliminary MFCA is to give an order of magnitude of the organization's total waste costs. The steps involved in a preliminary MFCA are as follows:

1. Define the scope
2. Calculate the cost of waste management
3. Calculate the waste material costs
4. Calculate the labour costs
5. Calculate the full cost of waste

Define the Scope

The first step is to define the physical and temporal limits of the analysis. For a preliminary MFCA, the analysis may cover the entire plant or a key process. The use of data available over a one-year period is suggested in order to include seasonal variations.

The following example applies costs of a fictitious organization as a whole over a period of one year.

Sample Interview with a Manager

Analyst: First of all, what waste containers do you currently have? And how much do you pay for the service?

Manager: We have a 6-cubic-yard container, lifted every week. Last year we paid a total of $21,200.

Analyst: What is usually found in the container? And in what proportion, approximately?

Manager: The container always leaves full! It's variable, about 50% plastic, 20% metal, 25% cardboard and the rest pallets.

Analyst: What raw materials do you buy annually, and at what price?

Manager: I don't have the exact figures, but we buy around 40 tonnes of plastic at around $5/kg and 25 tonnes of metal at $10/kg.

Analyst: On the labour side, how many employees do you have directly assigned to production? And what is their hourly rate?

Manager: There are 18 full-time employees, working 40 hours a week. They are paid an average of $25/hr.

Calculate the Cost of Waste Management

The analyst must estimate the total volume of residual materials generated for the given period. Invoices from suppliers of waste management services can help establish this volume. In the following example, we assume that waste management represents a cost of $21,200/year.

TABLE 6: **Estimating Total Waste Volume**

Container size	4,59 m^3
Space occupied by residual materials	× 100%
Number of lifts	x 1 lift/wk
Number of working weeks	x 50 wks
Total volume	**= 229,5 m^3**

Interviewing the company allows the analyst to determine the different waste generated. It's best to distinguish between each type of waste: packaging, production residues and non-conforming products.

At this stage, it is not necessary to know the exact proportion of each material: approximations are sufficient. Subsequently, volumes can be converted into weights using the apparent densities from the Worksheet - Preliminary MFCA.

TABLE 7: **Residual Materials**

Residual materials	**Proportion** (%)	**Volume** (m^3)	**Density** (kg/m^3)	**Estimated weight** (kg)
Plastic residues	50	115	× 60	= 6,885
Metal shavings	20	46	× 130	= 5,967
Plastic film	25	57	× 14	= 803
Pallets	5	11	× 150	= 1,721
TOTAL	**100**	**229,5**		**= 15,377**

Important

- A waste container rarely leaves full: the analyst must assess the volume actually occupied by residual materials.
- Service providers may charge a minimum tonnage for the collection of residual materials: the tonnage generated will then be overstated.
- Containers may include materials generated by office spaces, or materials that do not originate from manufacturing processes. We suggest ignoring these flows.
- Apparent density describes the space occupied by a residue and is different from its actual density. For example, while steel has a real density of around 7,500 kg/m^3, steel scrap occupies a space of 130 kg/m^3.

Calculate the Waste Material Costs

Using the weight of residual materials generated, we can determine the value of material costs.

TABLE 8: **Material Costs for Waste**

Residual materials	**Estimated weight** (kg)	**Purchase cost** ($/kg)	**Value** ($)
Plastic residues	= 6,885	× 5	= 34,42
Metal shavings	= 5,967	× 10	= 59,670
Plastic film	= 803	-	0
Pallet	= 1,721	-	0
TOTAL	**= 15,377**		**= 94,095 $**

Important

The cost of purchasing packaging is considered to be zero.

Calculate the Labour Costs

To complete the overall mass balance, the analyst can evaluate the organization's inputs.

TABLE 9: **Raw Materials Balance**

Raw materials	**Input quantity** (kg)	**Purchase cost** ($/kg)	**Cost of raw materials** ($)
Plastic	40,000	× 5	= 200,000
Metal	25,000	× 10	= 250,000
TOTAL	**65,000**		**= 450,000**

By comparing the mass of waste with that of inputs, we can determine the organization's overall loss rate.

Important

It is preferable not to count raw material packaging.

TABLE 10: **Overall Balance and Loss Rate**

Generation of residual materials (kg)	15,377
Consumption of raw materials (kg)	÷ 65,000
Overall loss rate	**= 24%**

The organization's overall loss rate is used to determine the labour cost attributable to the production and management of residual materials.

TABLE 11: **Workforce — Waste Production and Management**

Number of manufacturing employees	18
Normal working week	40 hr/wk
Number of working weeks	50 wks/yr
Average hourly rate	$25/hr
Direct labour cost	**= 900,000 $**
Overall loss rate	× 24%
Imputation factor (conservative)	× 25%
Estimated labour cost	**= 53,226 $**

Why an Imputation Factor?

Waste is generated throughout the production cycle, whether at the beginning (packaging), in the middle (production residues) or at the end (unsold products). Materials generated at the beginning of the cycle accumulate no labour costs, while materials generated at the end accumulate all direct labour costs. Since the preliminary MFCA does not provide for a detailed mass balance, a correction factor must be applied. The imputation rate chosen should represent the point at which waste is generated in the total product manufacturing time, on average.

Typically, most waste is generated at the beginning of the cycle, so an imputation rate of 25% might be realistic. However, if more precise information is available, an average imputation rate for all waste generated could be calculated and used for preliminary calculations. The simplified MFCA will enable this estimate to be refined.

Calculate the Full Cost of Waste

The information previously calculated is combined to estimate the full cost associated with the waste. A simplified MFCA is used to refine this estimate.

TABLE 12: **Full Cost of Waste**

	Full cost of waste ($)	**%**
Waste management	21,200	13
Waste material cost	94,095	56
Labour	53,226	32
TOTAL	**168,521**	**100**

Findings

- The preliminary analysis shows that the cost of waste management represents only a portion of the total cost of waste.
- Estimating the full cost of waste also gives an order of magnitude of the investments that could be made. For example, an investment of $250,000 to halve the full cost of waste would have a payback period of $250,000 / (50%*168,521) = 3 years.

TARGETED MFCA

The targeted MFCA focuses on a specific company process. This is the approach proposed by ISO 14053: 2001 *Environmental management — Material flow accounting — Recommendations for phased implementation in organizations.*

The steps for carrying out a targeted MFCA are as follows:

1. Define the scope
2. Calculate the cost of waste management
3. Calculate the waste material costs
4. Calculate the labour costs
5. Calculate the full cost of waste

Define the Scope

Since the targeted MFCA relates to a specific process within the organization, the first question to ask is: which process should be targeted? It may be appropriate to target one process:

- generating large quantities of waste, in particular production residues
- for which data is already available
- with no recycling loops or other complexities making analysis more difficult
- for which reduction solutions are already being considered by the organization or the analyst

These criteria will make it possible to quickly carry out an initial MFCA and provide relevant recommendations to the organization. They will also allow the organization and the analyst to familiarize themselves with the principles of MFCA and to determine whether a more in-depth study is relevant. If this is the case, the estimates made can be incorporated into a more complex model.

The targeted MFCA can focus on a specific process, or group together a set of processes, as long as cost and quantity estimates can be established. A description of the activities included and excluded from the analysis will enable the organization to provide the right estimates.

To illustrate the method, we use the example of a company fabricating chairs. It is determined that the targeted MFCA will focus on the first stage of production: molding the plastic seat. The main residue generated at this stage is a plastic residue following cutting. Data are reported over a 1-year period.

Calculate the Cost of Waste Management

The next step is to establish a simple mass balance of the process. By consulting the operators and the company's accounting data, the analyst can establish the quantities of inputs used, as well as the products and waste generated.

In the following example, the company uses large thermoplastic sheets, each with a unit weight of 25 kg. According to procurement data, 1,600 sheets are purchased each year, for a total weight of 40,000 kg. If we look at the residues following cutting, we see that the loss rate is 17%, or 6,800 kg/year. This information is summarized in the following table:

TABLE 13: **Mass Balance**

Input		**Product**		**Waste**	
Plastic	40,000 kg	Seats	33,200 kg	Scrap	6,800 kg
	100%		83%		17%

Waste management costs are then estimated. Waste management costs vary from company to company, depending on the contracts signed with service providers. Typical costs range from $100 to $500 per metric tons (mt). In some cases, the costs may be assumed by the municipality through selective collection, in which case the company pays no waste management costs. It is also possible that the company receives revenue for its residues. The analyst can refer to invoices from the collection service provider to identify the price currently paid by the company.

In this example, the company pays $100/mt. Scrap management costs are therefore estimated at $680/year.

Calculate the Waste Material Costs

The management cost does not take into account the value of what is thrown away. This is done by multiplying the quantity of material thrown away by the price paid for it.

For example, the company pays $125 per 25 kg sheet, which comes to a price of $5/kg. For the 40,000 kg purchased per year, this comes to $200,000 in material purchases. To calculate the material cost of the waste, we can multiply the price ($5/kg) by the quantity of waste generated (6,800 kg) to obtain a waste material cost of $34,000. Alternatively, we can multiply the material purchases ($200,000) by the loss rate (17%) to obtain the same material cost of $34,000.

TABLE 14: **Waste Material Costs**

	Input			Output			
				Products		Residues	
Materials	**Unit cost** ($/kg)	**Quantity** (kg)	**Cost** ($)	**Quantity** (kg)	**Cost** ($)	**Quantity** (kg)	**Cost** ($)
Plastic	5	40,000	200,000	33,200	166,000	6,800	34,000
Ratio		100%		83%		17%	

Complexity is added when intermediate products are used as inputs to the process under analysis. For example, plastic seats will be the input for the subsequent assembly stage. What price, then, should be placed on plastic seats? It's up to the analyst to choose an appropriate price. You can use the price of the materials used to make the seats ($5/kg), or document the price of a seat on the market.

Calculate Labour Costs

Direct labour is a major cost for manufacturing companies. The analyst must document the hourly labour rate as well as the work time for the process under study. The reject rate is then used to allocate part of the labour costs to waste.

In our example, the molding-cutting stage requires 21,000 hours/year. At an average hourly rate of $25/hr, this corresponds to a direct labour cost of $525,000. Since the wastage rate is 17%, we find that $89,250 is attributable to residue generation.

TABLE 15: **Labour Costs**

	Input			Output			
				Products		Residues	
Workforce	**Hourly rate** ($/hr)	**Time** (hr)	**Cost** ($)	**Ratio**	**Cost** ($)	**Ratio**	**Cost** ($)
Operators	25	21,000	525,000	83%	435,75o	17%	89,250

Other system costs can be treated in the same way: energy, water, equipment depreciation, etc. Preferably, only relevant and significant costs should be included (see the previous section, "Which Costs are Relevant and Significant?").

Calculate the Full Cost of Waste

Estimates of waste management costs, material costs and labour costs can then be combined to obtain the full cost of the waste. In this example, the full cost is $123,930. This estimate corresponds to the maximum savings the company could expect if reduction measures were implemented. It can also be used to establish a budget for process improvements.

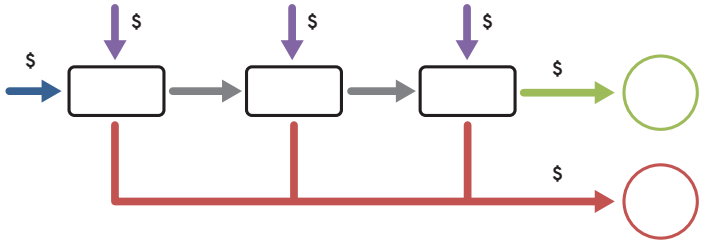
The information can be grouped together in a similar table:

TABLE 16: **Full Cost of Waste**

	Input			Output			
				Products		Residues	
Materials	**Unit cost** ($/kg)	**Quantity** (kg)	**Cost** ($)	**Quantity** (kg)	**Cost** ($)	**Quantity** (kg)	**Cost** ($)
Plastic	5	40,000	200,000	33,200	166,000	6,800	34,000
Ratio		100%		83%		17%	
Waste management costs	**Unit cost** ($/kg)	**Quantity** (kg)	**Cost** ($)			**Quantity** (kg)	**Cost** ($)
Container	0.1	6,800	680			6,800	680
Workforce	**Hourly rate** ($/hr)	**Time** (hr)	**Cost** ($)	**Ratio**	**Cost** ($)	**Ratio**	**Cost** ($)
Operators	25	21,000	525,000	83%	435,750	17 %	89,250
TOTAL			**725,680**		**601,750**		**123,930**

This exercise can be repeated for another of the company's critical processes. It may also be appropriate to model the entire company, as proposed in the next section.

SIMPLIFIED MFCA



The simplified MFCA provides a more detailed breakdown of the costs associated with waste, including labour costs and waste management costs, while at the same time making it possible to identify the production stages that generate this waste. The steps involved in a simplified MFCA are as follows:

1. Define the scope and process diagram
2. Calculate the cost of waste management
3. Calculate the material and system costs
4. Draw up a detailed mass balance
5. Calculate the cost of waste production
6. Calculate the full cost of waste

Define the Scope and Process Diagram

As in the preliminary MFCA, the physical and temporal limits of the analysis need to be determined. A period of 1 year is suggested in order to account for seasonal variations.

A process diagram details the quantity centres and flows (raw materials, intermediate products, waste, and final products). To build a process diagram:

1. List all of the organization's production stages. Best practice: include a step for waste management.
2. To identify quantity centres, exclude steps related to administration or that do not interact with raw materials or intermediate products.
3. Link quantity centres by identifying the use of resources, the transfer of intermediate products and the generation of residual materials.
4. If necessary, aggregate certain quantity centres to simplify the analysis.

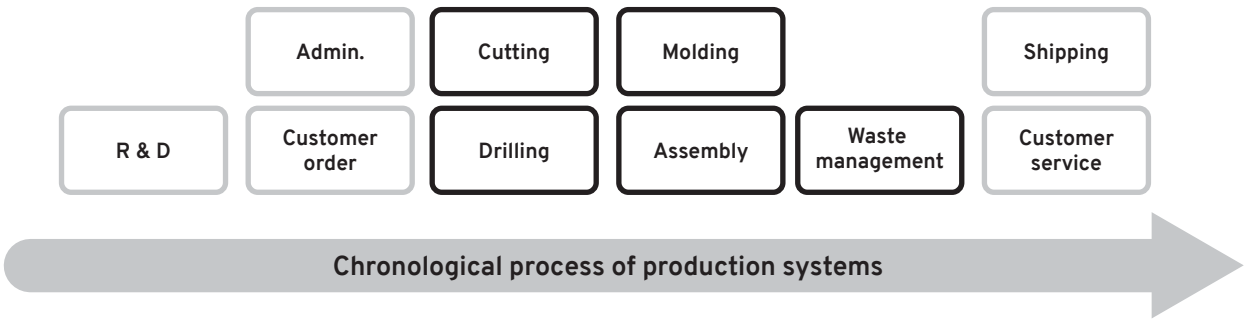


FIGURE 2: **List of Production Stages and Identification of Quantity Centres**

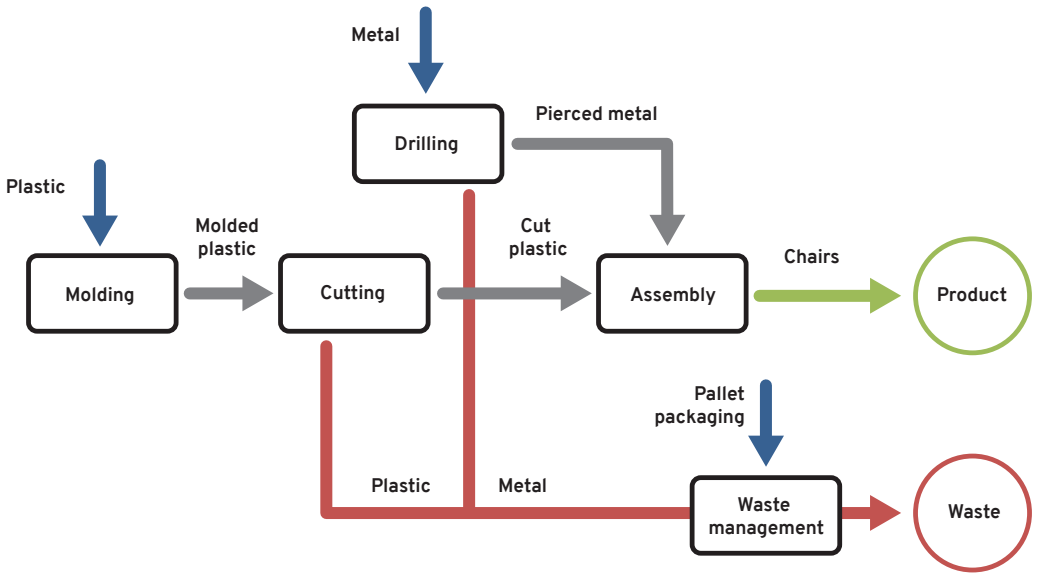


FIGURE 3: **Process Diagram**

Calculate the Cost of Waste Management

The analyst needs to assess the amount of time spent internally on waste management. This may include time spent sorting and transporting waste.

TABLE 17: **Internal Waste Management**

Direct labour (hr/year)	200
Average internal hourly rate ($/hr)	25
Total salary ($/year)	**5,000**

The organization may have several containers or areas set aside for waste management. For each of them, detail the fixed and variable costs and volumes. Fixed and variable rates for container rental are usually listed on invoices.

TABLE 18: **External Waste Management**

Container or batch of residual materials	**Fixed cost – container rental** ($/year)	**Variable costs – transport and disposal** ($/mt)	**Container volume** (m^3)	**Proportion occupied by waste** (%)	**Lift frequency** (lifts/year)	**Total volume** (m^3/year)
Container – waste	20,300	50.00	4.59 ×	100 ×	50 =	229.5
Space for pallets	-	-	0.2 ×	100 ×	50 =	10.0
TOTAL	**20,300**		**4.79**			**239.5**

A visual inspection of the containers can establish the different materials generated and the proportion occupied within the container. Their weight can be estimated by weighing or by using the apparent densities provided by the Worksheet - Simplified MFCA. If greater precision is required, a characterisation of residual materials can be carried out (CTTÉI, 2021)..

Internal management costs and fixed rental costs are allocated to waste by volume, while variable costs are allocated to waste by weight.

TABLE 19: **Waste Characterization**

Waste and unsold goods	**Container/ batch**	**Space occupied** (%)	**Volume** (m^3/ year)	**Estimated weight** (kg/year)	**Internal cost of waste mana-gement** ($/year)	**Fixed costs – container rental** ($/year)	**Cost of transport and disposal** ($/year)	**Waste mana-gement cost** ($/year)
Plastic residues	Waste container	50	115	6,885	2,396	10,150	344	12,890
Metal shavings	Waste container	25	57	7,459	1,198	5,075	373	6,646
Plastic film	Waste container	25	57	803	1,198	5,075	40	6,313
Pallets	Space for pallets	5	10	1,500	209	-	-	209
TOTAL		**100**	**239.5**	**16,647**	**5,000**	**20,300**	**757**	**26,057**

Should We Ignore Certain Types of Waste?

At this stage, it can be tempting to dismiss certain types of waste: if non-compliant products represent only 1% of the materials generated, can they be ignored? Yes, they can – however, analysis may reveal that certain small-volume materials are responsible for a large proportion of the total cost of waste.

As with the preliminary analysis, it is advisable to exclude materials generated by office spaces, or materials that do not originate from manufacturing processes. These flows are not likely to be modified by process changes.

Calculate Material and System Costs

Similar to the preliminary MFCA, the purchase cost of each raw material must be documented:

TABLE 20: **Material Costs**

Material or product	**Purchase** ($/year)	**Quantity purchased** (kg/year)
Plastic	200,000	40,000
Metal	250,000	25,000
TOTAL	**450,000**	**67,000**

Direct labour costs are also estimated for each quantity centre. In Table 21, the number of work hours and the internal hourly rate are used. The hours devoted to internal waste management have already been accounted for in Step 2.

TABLE 21: **System Costs**

Quantity centres	**Molding**	**Cutting**	**Drilling**	**Assembly**	**TOTAL**
Direct labour (h/year)	6,000	15,000	4,800	10,000	**35,800**
Average internal hourly rate ($/hr)	25.00	25.00	25.00	25.00	
Total salary ($/year)	150,000	375,000	120,000	250,000	**895,000**

If other system costs appear significant to the analyst, it may be useful to calculate them at this stage (see detailed MFCA).

Draw up a Detailed Mass Balance

A crucial step is to draw up a mass balance, following the process diagram determined earlier. For each quantity centre, the inputs used and outputs generated are determined. The information calculated in steps 2 and 3 can be used as a starting point.

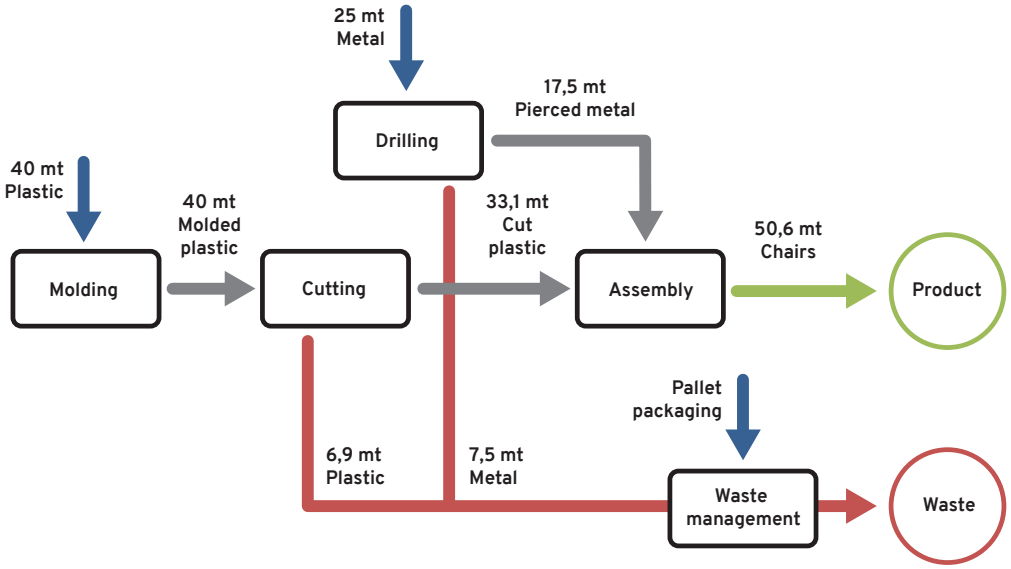


FIGURE 4: **Process Diagram**

Include Packaging?

Depending on the type of packaging, it may or may not be taken into account when calculating production costs. The mass balance should include any packaging which requires special labour, due to its nature or to the large quantities involved (e.g., disassembly of wooden crates). However, it is preferable not to include standard packaging at this stage, as this would distort the actual cost estimate.

Important

Ignoring inventory variations, the inputs and outputs of each quantity centre must balance. In the example above, we can verify that for assembly, 33.1 + 17.5 = 50.6.

Calculate the Waste Production Costs

For each quantity centre, the total cost of inputs is calculated as follows:

$$\text{inputs}\left[\frac{\$}{\text{yr}}\right] = \text{Materal costs} + \text{labor costs} + \text{other costs associated}$$

Input costs are allocated according to the mass proportion of each output:

$$\text{cost}_o\,[\$/\text{yr}] = \text{inputs}_c\,[\$/\text{yr}] \times \frac{\text{quantity}_o\,[\text{kg/yr}]}{\sum \text{quantity}_o\,[\text{kg/yr}]}$$

These calculations are repeated, from reception to distribution, until the production costs of each residual material and product have been determined. The Worksheet - Simplified MFCA facilitates this step.

L: Labor

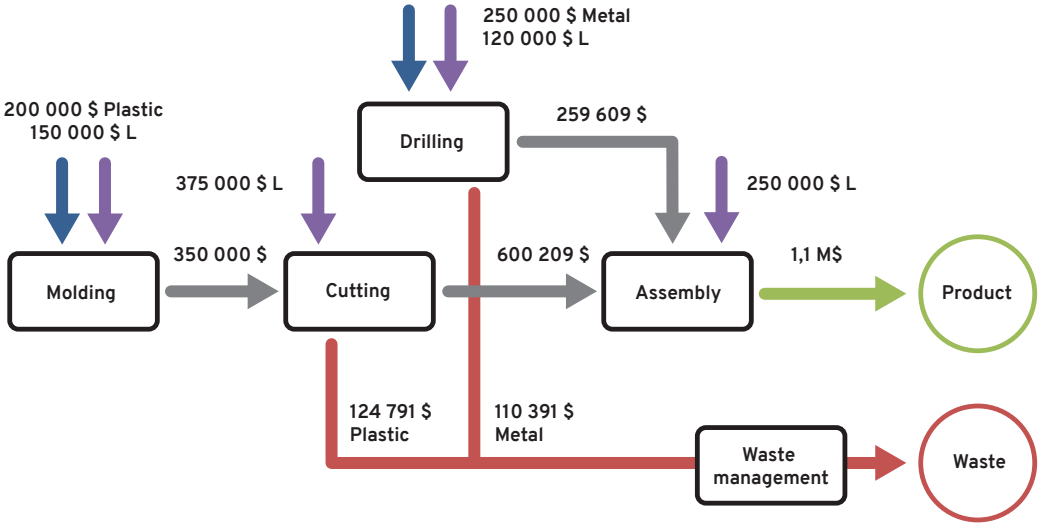


FIGURE 5: **Cost of Waste Production**

Calculate the Full Cost of Waste

The costs of waste management (step 2) and waste production (step 5) are aggregated are aggregated to obtain the full cost of waste.

TABLE 22: **Full Cost of Waste**

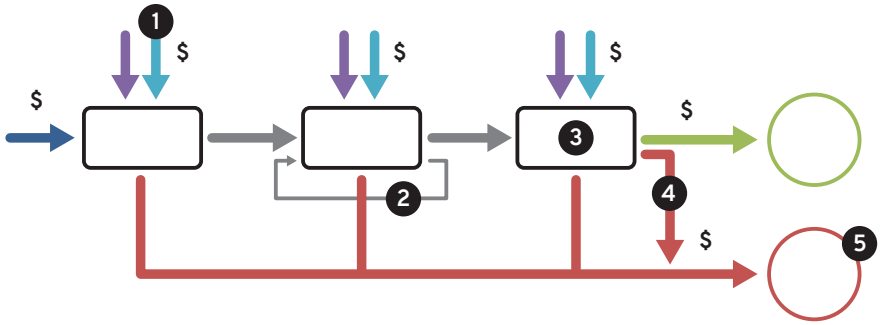
Waste	**Production cost** ($/period)	**Management cost** ($/period)	**Full cost** ($ $/period)	**%**
Plastic residues	124,791	12,890	137,680	53
Metal shavings	110,391	6,646	117,036	45
Plastic film	-	6,313	6,313	2
Pallets	-	209	209	0
TOTAL	**235,181 $**	**26,057 $**	**261,239 $**	**100 %**

Findings

In the example above, plastic film and pallets represent only 2% of the total cost of waste. An MFCA analysis usually concludes that industrial residues should be prioritized over packaging.

Similar to the preliminary analysis, we find that waste management represents only 10% of the total cost of waste.

DETAILED MFCA



As its name suggests, the simplified MFCA omits certain aspects presented by the ISO 14051 standard. To produce a detailed MFCA in compliance with the standard, the following elements, in addition to those already included in the simplified MFCA, must be considered:

1. Other system costs
2. Internal recycling
3. Inventory variations
4. Waste, wastewater and atmospheric emissions
5. Revenue

The detailed MFCA calculator integrates all of these elements.

Other System Costs

In the simplified MFCA, the only system cost considered is direct labour. The ISO 14051 standard considers other types of costs such as:

- Indirect manufacturing labour
- Process energy consumption[4]
- Variable water supply costs

4 ISO 14051 suggests integrating energy costs with material costs, or considering them separately from system costs.

Should Depreciation Be Taken into Account?

ISO 14051 allows equipment depreciation to be included in the analysis of the full cost of waste (ISO, 2011). However, this approach is discouraged by several authors (e.g., Schmidt, Götze, & Sygulla, 2015). While depreciation provides evidence of past investments, there is no associated cash flow. Taking depreciation into account could distort the interpretation of the full cost of waste, since this cost is not usually avoidable.

Equipment can be taken into account during the opportunity analysis phase. For example, the organization might consider purchasing a machine that generates fewer losses. The residual or market value of obsolete equipment can then be considered, as it will be sold.

Internal Recycling

In some cases, materials are recovered internally. The intermediate product is then considered as an input for another quantity centre. If the recycling process generates significant system costs, uses other inputs or itself generates residues, it is suggested that a second quantity centre be created. Even if internal recycling is desirable, an MFCA often reveals that reduction at source is preferable.

Inventory Variations

For the period under review, inventory variations may affect the mass balance. The value of positive or negative inventory variations is valued at the same price as raw materials or intermediate products.

Waste, Wastewater and Atmospheric Emissions

Non-conforming intermediate products, expired products, customer returns...for a variety of reasons, intermediate or final products can become residual materials. Their production and management costs are then added to the full cost of waste.

Some companies treat wastewater or atmospheric emissions. The costs of these activities can also be added to the full cost of waste.

Revenue

The company may generate income from the sale of residual materials. This can be considered in two ways:

- Comparing the full cost of waste with the revenue from its sale
- Integrating the revenues into the MFCA (Schmidt, Götze, & Sygulla, 2015)

An MFCA may reveal that the full cost of the waste exceeds the revenue, and that reduction at source is preferable.

OPPORTUNITY ANALYSIS

Once the MFCA has been carried out, it is important to analyze the different measures to reduce the total cost of waste. While some opportunities can be implemented quickly, others will require adapting processes and subsequent investment.

For each opportunity, two points need to be analyzed: the initial investment required (CAPEX) and the impact on operating costs (OPEX). Several indicators are then used to assess the profitability of an investment: internal rate of return (IRR), net present value (NPV) and payback period (PRI). For example, a project with a positive NPV is considered profitable in absolute terms. When comparing two opportunities, the one with the higher NPV should be given priority.

Initial investments may include:

- Negotiations with raw material suppliers
- Negotiations with waste management service providers
- Buying and selling equipment
- Storage space allocation
- Purchase of source sorting equipment
- Research & Development
- Staff training

The following table lists a number of opportunities for reducing the full cost of waste. The steps and investments required, as well as the impact on the full cost of waste, are specified.

To model the impact on operating costs, the Worksheet can be used by modifying the information on waste generated.

Findings

From an MFCA point of view, it is preferable to reduce at source rather than to recycle. Reducing waste at source lowers the total cost of waste as a whole (raw materials, labour, waste management, etc.), while external recycling only reduces waste management costs.

TABLE 23: **Impact of Opportunities on the Full Cost of Waste**

Opportunity	Stages and investments required	Impact on the total cost of waste				
		Cost of raw materials	Direct labour costs	Other system costs	Internal cost of waste mana-gement	External cost of waste mana-gement
Reduce scrap generation	R&D: manufacturing plans More efficient equipment Training	–	–	–	–	–
Opt for recyclable materials	R&D: alternative materials Source separation equipment Discussion with GMR supplier				±	±
Opt for reusable packaging	Discussion with supplier Storage space	±	±		–	–
Quality control at every stage		–	±	–	–	–
Reducing unsold stock	More efficient equipment Training	–	–	–	–	–
Reselling products with minor defects		–	–	–	–	–
Repairing defects	Repairing equipment		+	+	–	–
Creating industrial synergy	Discussion with other organizations nearby Storage space				+	±
In-house recycling	Storage space Recycling equipment	–	+	+	–	–
External recycling	Source separation equipment Training Discussion with GMR provider				+	±
In-house energy recovery	Storage space Equipment conversion		+	±	–	–
External energy recovery	Source separation equipment Training Discussion with GMR provider				+	±

DISTINCTION FROM OTHER APPROACHES

MFCA differs from other similar approaches, such as material flow analysis, total cost of ownership and job costing.

Material flow analysis (MFA) aims to trace the life cycle of a substance or product, from extraction to end-of-life. It usually focuses on an industry sector or region. It provides a consolidated map based on statistical data, characterizations and expert opinions. For example, an MFA on iron in Quebec identified that mined ores were mainly destined for export, while semi-finished and finished products were mostly imported (CIRAIG, 2016).

The **Total Cost of Ownership (TCO)** approach aims to compare the cost of two operations by taking into account all direct and indirect costs related to the purchase and use of a product or service (ECPAR, 2019). For example, a supplier charging a higher cost for its product may point to the savings generated by the customer during the use phase.

The **cost price** approach is used to evaluate the cost of manufacturing a product or service, in order to assess its profitability. Various manufacturing costs are allocated to each product in order to determine its "cost price". Waste management is seen as a necessary activity in the production of a good or service.

However, this approach contrasts with the organization's material and energy flow balance. In fact, a significant proportion of the materials purchased and processed are not sold and end up in waste containers. Also, part of the operations will have served only to produce material that will be thrown away.

It can be used to analyze an organization's activities in the recycling sector: for example, Éco Entreprises Québec used this method on the entire selective collection system to determine the cost of recycling each type of packaging (ÉEQ, 2016).

The TCO and cost price approaches take into account the costs associated with production and waste management. However, these expenses are perceived as normal product expenses. In comparison, the MFCA approach isolates the costs associated with material inefficiencies and enables us to target actions to be taken to improve waste management.

TABLE 24: **Distinction between Mfca and Other Similar Approaches**

Approach	Material flow cost analysis (MFCA)	Material flow analysis (MFA)	Total cost of ownership (TCO)	Cost price
Objective	Determine direct and indirect waste-related costs	Map material flows, from extraction/ import to end-of-life/ export	Supplier selection based on the total direct and indirect costs of a product/ service; Demonstrate the savings associated with a product with a higher acquisition cost	Determine the production cost and profitability of a product/service
Scope	All the flows of an organization or value chain	All flows in a value chain or region	All costs over the lifetime of a product/ service	All flows related to the production of a product/service

CONCLUSION

The MFCA is proving to be a relevant tool for improving waste management. The simpler variations and the tools that have been developed will enable more organizations to account for the full cost of waste. Above all, the MFCA is a circular economy tool, highlighting the economic stakes involved in waste production, so that action can be taken accordingly (waste recovery being the last of these actions). This tool therefore lays the foundations for developing an integrated approach to improving the efficiency of material use in the supply chain, by (i) optimizing the use of raw materials and/or (ii) modifying manufacturing processes.

In addition to an MFCA, a company can carry out a characterization of its residual materials (CTTÉI, 2021). Combining these two approaches, the analyst will have a better understanding of waste generation and associated costs.

While the MFCA has been presented here as an exercise carried out on an ad hoc basis, it is in an organization's best interest to calculate its balance sheet on a regular basis, whether to validate and analyze reduction opportunities or to quantify the benefits incurred. This is a first step for organizations towards a more circular economy.

REFERENCES

ADEME. (2014). *Full cost of waste*. Angers.

Christ, K. L., & Burritt, R. L. (2016). ISO 14051: A new era for MFCA implementation and research. *Revista de Contabilidad-Spanish Accounting Review*, 19(1), 1-9. https://doi.org/10.1016/j.rcsar.2015.01.006

CIRAIG. (2016). *Métaux et économie circulaire au québec - Rapport de l'étape 2.2 - Analyse de flux de matières du cuivre, du fer et du lithium*. Retrieved from https://mern.gouv.qc.ca/publications/mines/AFM-cuivre.pdf

CTTÉI (2021). Guide des meilleures pratiques - Caractérisation des matières résiduelles, 69 pages.

ECPAR. (2019). *TOTAL COST OF OWNERSHIP (TCO) DATA SHEET*. 1-7. Retrieved from https://www.ecpar.org/sites/ecpar.org/files/documents/fiche_technique_ctp_vf_web.pdf

ÉEQ. (2016). *Cost allocation by activity - 2016 results*. Retrieved from https://www.recyc-quebec.gouv.qc.ca/sites/default/files/documents/allocation-couts-activite-2016.pdf

Government of Quebec. *Environment Quality Act.* , (2017).

ISO. (2011). I*SO 14051 - Environmental management - Material flow accounting - General framework.*

Schmidt, A., Götze, U., & Sygulla, R. (2015). Extending the scope of Material Flow Cost Accounting - Methodical refinements and use case. *Journal of Cleaner Production*, 108, 1320-1332. https://doi.org/10.1016/j.jclepro.2014.10.039

APPENDIX 1 - CHECKLIST OF RELEVANT COSTS

Parameter/ information	Unit	Evaluation	Person to contact	Preliminary MFCA	Targeted MFCA	Simplified MFCA	Detailed MFCA
Sourcing							
Cost of raw materials	$	by material	accounting	●	●	●	●
Quantities purchased	mt, un.	by material	accounting, manu facturing	●	●	●	●
Purchase cost	$/mt, $/un.	by material	accounting, manu facturing	●	●	●	●
Processes using raw materials	weight %, mt	for each input and by quantity centre	manu-facturing			●	●
Energy costs	$/kWh	by quantity centre	accounting				optional
Variable water costs	$/m^3	by quantity centre	accounting				optional
Manufacturing							
Direct labour costs	$	global	accounting	●	●	●	●
Average hourly rate	$/h	global	accounting	●			
Hourly rate	$/h	by quantity centre	accounting		●	●	●
Number of working weeks	wks/year	global	accounting	●	●	●	●
Total direct labour	h	global	accounting, manu-facturing	●			
Direct labour	h	by quantity centre	accounting, manu-facturing		●	●	●
Indirect manufacturing labour	$	by centre	accounting				optional
Consumption of intermediate products	mt	for each product and by quantity centre	manu-facturing		●	●	●
Change in inventories	mt	by input and product	accounting, manu-facturing				●
Total quantity of outputs	mt	k end products	accounting, manu-facturing		●	●	●

Parameter/ information	Unit	Evaluation	Person to contact	Preliminary MFCA	Targeted MFCA	Simplified MFCA	Detailed MFCA
Residual materials management							
Cost of waste management	$	global	accounting	●	●	●	●
Fixed costs	$	per container	accounting			●	●
Variable weight charge	$/mt	per container	accounting			●	●
Total quantity of residual materials	mt	global	accounting	●	●	●	●
Total container volume	m^3, v^3	global	accounting	●			
Container volume	m^3, v^3	per container	accounting			●	●
Average lift frequency	lifts/year	global	accounting	●			
Lifting frequencies	lifts/year	per container	accounting			●	●
Average space occupied by residual materials	% volume	global	manu-facturing	●			
Space occupied by residual materials	% volume	per container	manu-facturing			●	●
Space occupied by each material in the containers	% volume	per waste	manu-facturing	●		●	●
Other GMR-related system costs	$	per waste	manu-facturing				optionnal
Waste-generating processes	weight %, mt	for each waste and by quantity centre	manu-facturing		●	●	●
Internal labour costs related to GMR	$	global	accounting		●	●	●
Internal hourly rate	$/h	global	accounting			●	●
Time spent managing residual materials	h	global	manu-facturing			●	●
Other							
Equipment depreciation	$	By equipment	accounting				optionnal
Market value of equip-ment	$	By equipment	comptabilité				optionnal

APPENDIX 2 – MAPPING THE PATH OF AN MFCA

Analysis steps	Estimated time
Preliminary analysis	**9h**
First virtual meeting with the company	2h
Data processing and MFCA production	3h
Final report writing	2h
Presentation of results and final validation of data and recommendations	1h
Follow-up on recommendations	1h
Targeted analysis	**18h**
First virtual meeting with the company	2h
Map production	3h
Data processing and MFCA production	5h
Validation of data and hypotheses with the company	1h
Internal meeting to formulate recommendations	1h
Final drafting of the report	3h
Presentation of results and final validation of data and recommendations	2h
Follow-up on recommendations	1h
Simplified analysis	**41h**
First virtual meeting with the company	2h
Map production	5h
Company visit	3h
Data processing and MFCA production	15h
Validation of data and hypotheses with the company	4h
Internal meeting to formulate recommendations	2h
Final drafting of the report	4h
Presentation of results and final validation of data and recommendations	5h
Follow-up on recommendations	1h
Detailed analysis	**55h**
First virtual meeting with the company	2h
Map production	5h
Company visit	3h
Data processing and MFCA production	25h
Validation of data and hypotheses with the company	5h
Internal meeting to formulate recommendations	2h
Final drafting of the report	7h
Presentation of results and final validation of data and recommendations	5h
Follow-up on recommendations	1h

cttéi

UNIVERSITÉ LAVAL | Centre de recherche en comptabilité et développement durable

9 782982 069053