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Selecting Organic Waste Treatment Technologies

SOWATT

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Acronyms

AD:	Anaerobic digestion
BSF:	Black Soldier Fly
CBO:	Community Based Organizations
CENRO:	City Environment and Natural Resource Officer
C:N:	Carbon and Nitrogen Ratio
CSF:	City of San Fernando
CSWMB:	City Solid Waste Management Board
DBO:	Design-Built-Operate
FC:	Fixed Carbon
GHG:	Green House Gas
GSO:	General Service Officer
GWP:	Global Warming Potential
HHV:	High Heating Value
IEC:	Information, Education and Communication
IER:	Income Expenditure Ratio
LGU:	Local Government Unit
LHV:	Low Heating Value
MAVT:	Multi Attribute Value Theory
MCDA:	Multi Criteria Decision Analysis
MC:	Moisture content
MRF:	Material Recovery Facility
NGO:	Non Governmental Organization
NIHL:	Noise Induced Hearing Loss
NL:	Normal litters. Volume in liters at normal conditions
ODTS:	Organic Dust Toxic Syndrome
OFMSW:	Organic Fraction of Municipal Solid Waste
OLR:	Organic Loading Rate
O&M:	Operational and Maintenance
PAH:	Polycyclic Aromatic Hydrocarbons
PCO:	Pollution Control Officer
PHP:	Philippine Peso
RH:	Relative Humidity
SLF:	Sanitary Landfill
SOWATT:	Selecting Organic Waste Treatment Technologies
SP:	Slow Pyrolysis
SWM:	Solid Waste Management
SWAPP:	Solid Waste Association of the Philippines
TS:	Total Solids
VOC:	Volatile Organic Compounds
VS:	Volatile Solids
WACS:	Waste Amount and Characterization Study
WM:	Waste Management

Introduction

Figure 1

Municipal solid waste continues to be a challenge for municipal authorities, and finding best practices and appropriate solutions for its management is of great interest to municipal officers. Municipal organic waste, also called biowaste, constitutes the main fraction of municipal solid waste in low- and middle-income settings. Often, more than 50% of all municipal solid waste is organic and easily biodegradable. Illegal and uncontrolled disposal of solid waste that contains a high percentage of biowaste leads to the generation of methane (a potent greenhouse gas), as well as landfill leachate, that may pollute groundwater and surface water. Finally, biowaste, if managed inappropriately, attracts animals and disease vectors and, thus, puts human health at risk.

Whereas in the past, the priority of waste management was the collection and removal of waste with subsequent disposal, the importance of resource recovery and recycling is attracting more attention and priority. Along with this increasing paradigm change focusing on resource recovery, new approaches for the management of biowaste with respective treatment technologies are becoming more popular. We developed the SOWATT manual: **S**electing **O**rganic **W**aste **T**reatment **T**echnologies to help structure and assist in the process of comparing and selecting the most promising biowaste treatment options for a given case study.

The underlying concept is that biowaste has a value and that recycling biowaste can contribute to the economic and environmental sustainability of solid waste management.

As a reader of this manual, you have probably recognized the potential of biowaste treatment, but still face the challenge of what to do about it. You might have witnessed that biowaste is often not recycled and past experience shows that many biowaste treatment initiatives have failed. Composting facilities for instance – the most well-known approach of biowaste processing – have often been abandoned shortly after implementation. Why can these not be sustained for longer periods of time?

Regardless of what treatment technology is applied to manage organic waste, durability and sustainability rely on various key factors and contextual conditions. In this manual, we distinguish the following different factors that influence the feasibility of an organic waste treatment approach:

1. Technical feasibility: includes the land area required to implement the technology, the skills and capacity necessary to build and operate it and the waste feedstock quantity and quality the technology can treat.
2. Economic feasibility: comprises the capital and operational costs of the treatment facility, as well as the revenue streams possible from sales of the products derived from waste by the specific treatment technology.
3. Social impact: considers aspects, such as job creation, as well as health threats that a technology may pose to the workers and the communities living or working nearby.

Careful evaluation of each organic waste treatment against the factors mentioned above can help improve the making of informed decisions on what type of treatment technology to select. Unfortunately, this seldom happens.

WHY IS SELECTING A BIOWASTE TECHNOLOGY COMPLEX?

Many factors need to be considered in order to ensure the long-lasting success of any biowaste treatment initiative. Since many biowaste treatment technologies exist, it is crucial to first evaluate the influencing factors with regard to the different alternatives available and only then - based on the assessment - make a decision on what approach to pursue.

Unfortunately, in the past, the factors influencing success have mostly been neglected in decision making. Decisions were rather made based on successful sales promotion by vendors or a fallback on the most well-known technology, such as composting. But, before taking such a decision, questions should be posed and answered satisfactorily. A default choice for composting should be questioned, for instance, by asking:

- What is the objective of a composting facility?
- Why is composting better than any other choice to reach this objective?
- What will be done with the compost produced?
- Is there a need to compost in the area (e.g. for soil amendment)?
- Is there a demand for compost?

As a decision maker or a technical expert preparing the necessary information for decision makers, you will notice that the deeper you get involved in the decision problem, the more challenging it becomes and the more it requires an analysis of trade-offs.

THE NEED FOR A STRUCTURED DECISION APPROACH

Waste management related decisions are complex and require the consideration of many influencing factors and alternative solutions. Tackling this needs attention and careful deliberation. A structured approach for evaluation and to support the decision-making process helps in this complex task.

This manual will help to structure and guide you through the specific task of selecting a biowaste treatment technology for a given case study.

Decision analysis science, with its tools and methods, provides a structure and a course of action to maximise the benefits from a decision. The basic assumption of decision analysis is that a complex decision problem can be solved more effectively by dividing it into several components. This manual follows a multi-criteria decision analysis approach (MCDA) called "Multi Attribute Value Theory (MAVT)". MAVT is a way to structure and solve decision and planning problems that involve multiple decision criteria. Typically, there is not one unique, optimal solution for such a problem context and it is, therefore, necessary to apply preferences to differentiate between potential solutions.

This manual does not cover everything there is to know about decision-making. For those interested in learning more about this, we recommend the book entitled *Rational Decision Making (Eisenführ et al., 2010) and Structured Decision Making. A Practical Guide to Environmental Management Choices (Gregory et al., 2012).* This manual introduces the key principles, which include understanding the decision problem, introducing the objective hierarchy and corresponding attributes, presenting the alternatives, elicitation of preferences by stakeholders, as well as analysing, illustrating and interpreting the results.

WHO ARE POTENTIAL USERS OF THIS MANUAL?

This manual is for individuals or organisations, such as:

- Local authorities wanting to invest in, implement or operate a biowaste treatment facility.
- Entrepreneurs and private investors intending to set up a biowaste treatment facility as a business venture or social enterprise.
- Non-Governmental Organizations (NGOs) and civil society organizations wanting to make an improvement in the solid waste sector.
- Donor agencies deciding to help plan, support and fund biowaste treatment projects.

This manual tries to avoid complicated calculations, software or complex statistics. Nevertheless, some basic mathematical operations are required. We further suggest specific data that needs to be collected and analysed for the specific local context of the decision problem. Methods of data collection are explained and simple calculations can be conducted with any conventional spreadsheet software (e.g. Excel) or a calculator.

WHO MUST BE INVOLVED WHEN USING THIS MANUAL?

There are three main stakeholders involved in the process of this manual:

1) The person conducting the assessment (ideally the person reading this manual and referred to as "You" from now on),
2) Local experts who understand and know about the local context. They will provide the information to estimate the performance of the technologies (i.e. availability of several resources, such as water, energy and labour, or costs of different materials, etc.) (Step 5),
3) Relevant stakeholders whose preferences will be elicited (Step 6).

Ideally, the experts and relevant stakeholders should not be the same. However, sometimes it will be unavoidable to involve the same person in both roles.

HOW DOES THIS MANUAL HELP?

- It provides in-depth information on six different biowaste treatment technologies;
- It broadens the reader's knowledge of the existing waste situation in the selected case study;
- It broadens the reader's knowledge of different biowaste treatment options;
- It guides the reader in comparing different potential biowaste treatment technologies for a specific city or neighbourhood;
- It highlights the main weaknesses and strengths of each potential technology for a given context;
- It helps identify the key technical, social, economic and environmental parameters that influence the feasibility and performance of different biowaste treatment technologies;
- It suggests ways to communicate the results in a comprehensive and visual manner

However, this manual has some limitations. As it is not written for a specific country or context, it elaborates on the aspects of biowaste management from a more general and global perspective so that the knowledge can be applied in a variety of settings. Such generalisation requires simplification and general assumptions. Some general data provided in this manual may not be precise enough or applicable to the specific case study. We consider the lack of precision an acceptable trade-off with regard to the broad applicability of the manual. We welcome feedback and suggestions from readers and users for an eventual specific adaptation of this manual to a local context.

We would again like to point out that this manual **does not decide for you** which biowaste technology shall be implemented. Rather, it helps prepare the grounds for informed decision making by providing essential information and suggesting what other information needs to be collected for specific case contexts.

STRUCTURE

The manual is structured in two parts:

PART 1: Introduces the issues of biowaste treatment while defining the concept of biowaste and its treatment options.
PART 2: Presents the stepwise approach to support the selection of a biowaste treatment option. This part consists of nine Steps.

Step 1: *What is your problem?- Framing the problem*
Step 2: *Who should you involve? – Stakeholder analysis*
Step 3: *Which technologies should you consider? – Identifying alternatives*
Step 4: *How do you choose among different technologies?- Objectives and attributes*
Step 5: *How do the technologies perform for each objective?- Performance estimation*
Step 6: *What is the relative importance between objectives?- Workshops to elicit preferences*
Step 7: *What is the final score of each technology? - Data analysis*
Step 8: *Displaying and interpreting results*
Step 9: *Final discussion*

Throughout the second part, besides introducing the required methodologies to tackle every Step, we illustrate the Steps by providing a real-case-study based example – the City of San Fernando (CSF), Philippines. Annex 1 presents a description of the CSF case study in detail.

Biowaste Management

WHAT IS BIOWASTE?

Before reading further, let's briefly reflect on the following questions:

- What is biowaste?
- Why is biowaste treatment important?
- What kinds of technologies exist to treat biowaste?

The term biowaste refers to the Organic Fraction of Municipal Solid Waste (OFMSW). It differs from the terms "organic waste" and "biodegradable waste", which are often confused as the same.

- **Biodegradable waste refers to all sorts of organic wastes:** Biodegradable waste refers to all sorts of organic wastes

  Definition: "biodegradable waste is any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food, garden waste, agricultural waste, animal waste, paper and paperboard."

- **Biowaste refers to a subset of biodegradable waste**

  Definition: "biowaste comprises only biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises and comparable waste from food processing plants"

Figure 2 depicts potential sources of biodegradable waste and biowaste.

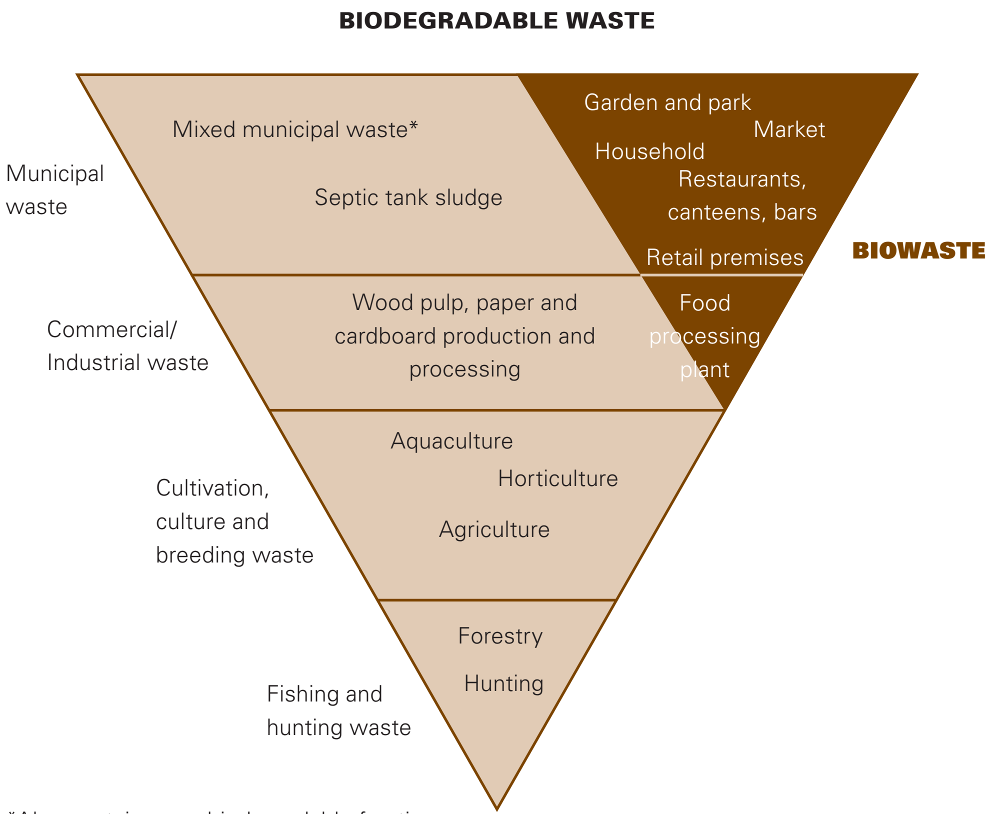

Figure 2: Potential sources of biodegradable waste and biowaste

WHY IS BIOWASTE TREATMENT IMPORTANT?

Biowaste naturally degrades through biological activity. This may happen aerobically (with oxygen) or anaerobically (without oxygen). Large amounts of biowaste, degrading in an uncontrolled manner, may generate harmful environmental and health impacts (Table 1). These impacts relate to greenhouse gas emissions and global warming; pollution of soil, water and air; the spread of disease vectors and negative economic impacts.

Table 1: Potential impacts of unmanaged biowaste

Element	Negative impact	Consequence
Soil	Contamination of soil through leachate	Deterioration of public and environmental health
	Devaluation of the fields	Economic costs
Water	Contamination of groundwater through leachate	Deterioration of public and environmental health
	Need for water treatment downstream	Economic costs
Air	Release of greenhouse gases (e.g.: methane)	Global warming
	Bad smell	Deterioration of comfort and public health
Other	Promoting/attracting disease carrying vectors (flies, rodents, etc.)	Deterioration of public health
	Visual pollution	Tourism

Furthermore, the wet and high density nature of biowaste (Table 2), affects not only the choice of collection and transport systems, but also the choice of treatment technology. The good news is that there are relatively low-cost treatment methods to treat and transform biowaste into a natural resource. These methods can also produce products from biowaste that have a value for users of this product and, therefore, offer a more sustainable course of action than the "business-as-usual" approach of open dumping and unsanitary landfilling.

Table 2: Density and wet content per waste type (Chandrappa et al., 2012)

Type	Density [kg/m³]	Water content[%]
Food waste	120 - 480	50 - 80
Garden trimmings	60 - 225	30 - 80
Wood	156 - 900	15 - 40
Paper	30 - 130	4 - 10
Plastic	30 - 156	1 - 4

EXAMPLES OF BIOWASTE TREATMENT TECHNOLOGIES

Each treatment technology generates different products of value. This manual covers six potential technologies:

1) Windrow composting
2) In-vessel composting (and Bin-composting)
3) Vermicomposting
4) Anaerobic digestion
5) Slow pyrolysis
6) Black Soldier Fly processing

Figure 3

WINDROW COMPOSTING

Composting is a microbiological process through which organic materials are transformed into a stable, dark brown, soil-like material called compost. This process occurs by way of microbial activity under aerobic conditions (i.e. in the presence of oxygen).

Biodegradable waste is piled up in long heaps (windrows). During the process of material degradation, temperatures as high as 70°C can be reached in the centre of the piles. This high temperature contributes to the hygienisation of the piles by partially eliminating pathogens and weed seeds.

Controlling the process implies that the predominant parameters, such as organic material composition (carbon–nitrogen ratio), particle size, free air space, aeration, temperature, moisture, and pH, are managed, steered and adjusted to achieve fast degradation and good compost quality. When conditions are not optimal, the process may be slowed or may not happen at all.

We distinguish two alternatives:

1) Small scale or self-use windrow composting plants, which tend to be manually operated
2) Medium to large scale commercial windrow composting plants, which tend to include more equipment and mechanisation.

Table 3: Technical considerations and suitable biowaste for windrow composting

Technical consideration	**Lifetime installation[1]:**	15-30 years
	Processing time[2]:	3-6 months
	Mass reduction:	35-40%
	Labour (n° of operators):	1 – 2 (<1 ton/day) or 1 – 2.5 (> 1 ton/day)
	Operating temperatures:	>0°C (big piles) or >15°C (small piles)
	Surface needs:	180 – 300 m^2 per 1 ton/day
	Water needs:	5 - 100 L/ton
	Energy needs[3]:	30 – 55 kWh/ton or none (manual)
	[1]Depends on construction materials; [2]Depends on operation; [3]If Commercial scale, energy needs will depend on machinery used and the demands for electrical installation (see r equipment list).	

Suitable biowaste	**Range of acceptable Moisture:**	Coarse: 70-75%; Fine: 55 – 65%
	Range of acceptable C:N:	20 – 50
	pH	5.5 – 7.5
	Examples - suitable:	**Examples - unsuitable:**
	- Garden trimmings - Vegetable waste - Fruit waste - Fish or meat waste - Animal manure	- Big chunks of woody materials, coconut shells - Feedstock with high salt content or other plant damaging pollutants - Feedstocks with high oil or fat content

Table 4 shows the materials needed in alphabetical order for a small-scale plant (self-use) and a medium/large scale plant (commercial use), as well as the final products and suggested literature for this technology. The essential operating equipment is shown in ***bold and italics.***

Table 4: Equipment, products and references for windrow composting

	Small scale (self-use)	Medium / big scale (commercial)
Equipment	• Aeration frame • Bags ***• Bucket/Water hose*** ***• Cover material (plastic sheets, fibres, etc.)*** ***• Knife/machete*** • Protection equipment (gloves, face mask, etc.) • Record keeping material (monitoring sheets, pens, folders, etc.) • Scale ***• Shovel/Fork*** • Sieve • Thermometer ***• Wheel barrow / Bucket***	• Aerator (ventilator) • Bagging machine + Spare parts ***• Bags*** ***• Bucket/Water hose*** ***• Cover material/Roofing*** • Flooring (concrete, with leachate collection) • Generator + Spare parts • Office construction (office furniture, toilets, showers, etc.) • Pump (leachate recirculation) • Protection equipment (gloves, face mask, etc.) ***• Record keeping material (monitoring sheets, pens, folders, etc.)*** • Scale ***• Shredder + spare parts*** ***• Skid loader or Compost turner/ Shovel or Fork*** ***• Sieve*** ***• Thermometer*** ***• Wheel barrow/Small truck (+ Spare parts)***

Product

The main output product from composting is compost: a stable dark-brown, soil-like material with a crumbly texture, dark colour and earthy smell. It can be used as a soil amendment and its quality depends on the feedstock and quality control during the process. Its use depends on the quality of the final products and legislation.

Besides compost, other output products emitted during the composting process are leachate, water vapour and carbon dioxide.

Figure 4

Ref.

Cooperband (2002); Rothenberger et al. (2006); Lohri et al. (2017)

IN-VESSEL COMPOSTING (AND BIN COMPOSTING)

In-vessel composting is the same process described above in composting; however, instead of windrows, it uses rotating vessels that are turned manually or mechanically. This technology accelerates the composting process since it allows for improved aeration.

We distinguish between two alternatives:

1) Small scale or self-use in-vessel composting plants, which tend to be manually operated. If the vessels are not rotary, this approach is also referred to as "bin composting" (Figure 5 right).

Figure 5: Small scale In-vessel composting drums (left) and Bin composting in India (right)

2) Medium to large scale commercial plants, which tend to include more equipment and mechanisation (Figure 5). The mechanised option of this technology allows for steering and adjusting process parameters, such as aeration, temperature and moisture content, achieving a faster degradation process.

Table 5: Technical consideration and suitable biowaste for in-vessel composting

Technical consideration	**Lifetime installation[1]:**	15-30 years
	Processing time[2]:	2 – 3 months
	Mass reduction:	35 – 50%
	Labour (n° of operators):	1 (<1 ton/day) or 1 – 2 (> 1 ton/day)
	Operating temperatures:	- Non-heated: >0°C (big vessels) or >15°C (small vessels) - Heated: non-influential
	Surface needs:	85 m^2 per 1 ton/day
	Water needs:	5 – 60 L/ton
	Energy needs[3]:	165 - 190 kWh/ton or none (manual)
	[1] Depends on maintenance; [2] Depends on operation; [3] If Commercial scale, energy needs will depend on machinery used and the demands for electrical installation (see r equipment list).	

Suitable biowaste		
	Range of acceptable Moisture:	Coarse: 70-75%; Fine: 55 – 65%
	Range of acceptable C:N:	20 – 50
	pH	5.5 – 7.5
	Examples - suitable:	**Examples - unsuitable:**
	- Garden trimmings - Vegetable waste - Fruit waste - Fish or meat waste - Animal manure	- Big chunks of woody materials, coconut shells - Feedstock with high salt content or other plant damaging pollutants - Feedstocks with high oil or fat content

Table 6 shows the materials needed in alphabetical order for a small-scale plant (self-use) and a medium/large scale plant (commercial use), as well as the final products and suggested literature for this technology. The essential equipment for a plant to operate is shown in ***bold and italics.***

Table 6: Equipment, products and references for in-vessel composting

	Small scale (self-use)	Medium / big scale (commercial)
Equipment	• *Bags* • ***Bucket/Water hose*** • ***Knife/machete*** • *Protection equipment (gloves, face mask, etc.)* • *Record keeping material (monitoring sheets, pens, folders, etc.)* • *Scale* • ***Shovel/Fork*** • *Sieve* • *Thermometer* • ***Vessel container*** • ***Wheel barrow/Bucket***	• Bagging machine + Spare parts • ***Bags*** • ***Bucket/Water hose*** • Flooring (levelling) • Generator + Spare parts • Office construction (office furniture, toilets, showers, etc.) • Protection equipment (gloves, face mask, etc.) • ***Record keeping material (monitoring sheets, pens, folders, etc.)*** • Scale • ***Skid loader/Shovel or Fork*** • ***Shredder + Spare parts*** • ***Sieve*** • ***Thermometer*** • ***Vessel container (with turning engine + Spare parts)*** • ***Wheel barrow/Small truck (+ Spare parts)***

Prod.	The main output product from in-vessel composting is also compost (see Table 4).

Ref.	Cooperband (2002); Rothenberger et al. (2006); TNA (2012); Lohri et al. (2017)

Figure 6

Figure 7: Worms feeding on organic material (photo by Allan Henderson ©)

VERMICOMPOSTING

Vermicomposting is defined as the aerobic degradation and stabilisation of organic material by microorganisms and earthworms under controlled conditions. Microbial communities help degrade organic matter through a first step of aerobic degradation. Then, a high density of earthworms feed on the waste and generates earthworm castings, also called vermicompost.

The earthworms promote microbial activity by producing microbial-active material (vermicompost) with improved nutritional quality than compost. *Eisenia fetida* is the most frequently used species of worms.

The complete life cycle of E. *fetida* is around 70 days, and they double their weight every 60 – 90 days. The worms are mature after approximately 50 days, and start to produce cocoons after 55 days (i.e. 4–5 days after mating). The incubation period of the cocoons is approximately 23 days. Normal densities of worm population range between 2.5 - 5 kg worms/m².

Table 7: Technical considerations and suitable biowaste for vermicomposting

Technical consideration		
	Lifetime installation[1]:	15-30 years
	Processing time:	1.5 – 2.5 months
	Mass reduction:	40-80%
	Labour (n° of operators):	1 – 2 (<1 ton/day) or 1 – 2 (> 1 ton/day)
	Operating temperatures:	Min: 15°C, Opt: 20 – 25°C , Max: 35°C
	Surface needs:	300 – 580 m² per 1 ton/day
	Water needs:	5 - 40 L/ton
	Energy needs[2]:	30 – 55 kWh/ton or none (manual)
	[1] Depends on construction materials; [2] If Commercial scale, energy needs will depend on machinery used and the demands for electrical installation (see equipment list).	

Suitable biowaste		
	Range of acceptable Moisture:	70 – 90%
	Range of acceptable C:N:	10 - 25
	pH	Acceptable: 4.5 – 9, Optimum: 7.5 - 8
	Examples - suitable:	**Examples - unsuitable:**
	- Vegetable waste - Fruit waste - Animal manure - OFMSW	- Big chunks of woody materials, coconut shells - Fish or meat waste - Dairy products - Grease and oils - Salty and vinegary foods

[1]C:N: Carbon Nitrogen ratio

Table 8 shows the material needed in alphabetical order for a small scale plant (self-use) and a medium/large scale plant (commercial use), as well as the final products and suggested literature for this technology. The essential equipment for a plant to operate is shown in ***bold and italics.***

Table 8: Equipment, products and references for vermicomposting

	Small scale (self-use)	Medium / big scale (commercial)
Equipment	***• Ant traps*** *• Bags* ***• Bedding material*** *• Bucket/Water hose* ***• Containers/worm bed (concrete, plastic, etc.)*** ***• Cover material (plastic sheets, fibres, etc.)*** ***• Knife/machete*** *• Protection equipment (gloves, face mask, etc.)* *• Record keeping material (monitoring sheets, pens, folders, etc.)* *• Scale* ***• Shovel/Fork*** *• Sieve* ***• Wheel barrow/Bucket*** ***• Worms***	***• Ant traps*** *• Bagging machine + Spare parts* ***• Bags*** ***• Bedding material*** ***• Bucket/water hose*** ***• Cover material (plastic sheets, fibres, etc.)*** ***• Flooring and bed structure (concrete, bricks, etc.)*** *• Generator* *• Light* *• Office construction (office furniture, toilets, showers, etc.)* *• Protection equipment (gloves, face mask, etc.)* ***• Record keeping material (monitoring sheets, pens, folders, etc.)*** *• Roofing* ***• Scale*** ***• Skid loader/Shovel or Fork*** ***• Shredder*** ***• Sieve*** *• Table* ***• Wheel barrow/Small truck (+ Spare parts)*** ***• Worms***

Product	The main products resulting from vermicomposting are vermicompost, leachate (worm tea) and the worms. The vermicompost is a stable, dark-brown, granular, soil-like material. The grinding effect in the gut of the earthworms leads to the formation of these granules, which is a typical feature of vermicompost, and research has shown that it has higher levels of nutrients than compost. Leachate from the worm bins can also be used as a liquid fertiliser, which is typically used in small-scale systems. The earthworms are rich in protein (65%) and contain all essential amino acids required for animal feed. They are considered a good pro-biotic feed or are used as an additive for fish or poultry feed.

Figure 8

Ref.	Munroe (2007); Ali et al. (2015); Lohri et al. (2017)

ANAEROBIC DIGESTION

Anaerobic digestion is a microbiological process through which organic materials are biochemically decomposed while generating a fuel gas (biogas) and nutrient-rich digestate. This process occurs as a result of microbial activity under anaerobic conditions (i.e. in absence of oxygen). It is common to many natural environments, such as swamps or the stomachs of ruminants. The three main types of digesters considered in this manual are: the fixed-dome digester, the floating-drum digester and the tubular digester (see Figure 9). Detailed descriptions of each are provided in the coming pages. Table 9 shows the characteristics shared by the three digester types.

Figure 9: Different anaerobic digesters. A fixed dome digester under construction; a floating dome digester and a balloon digester, from right to left.

Table 9: Technical considerations and suitable biowaste for anaerobic digestion

Technical consideration	**Lifetime installation (years)[1]:**	Fixed-dome: 15 – 20 Floating-dome: 3 – 5 (humid climate), 8 – 12 (dry climate) Tubular: 2 – 5
	Processing time[2]:	10 – 40 days
	Mass reduction[3]:	0 – 20% (if water in digestate is considered)
	Labour (n° of operators):	1 (<1 ton/day) or 1 – 2 (> 1 ton/day)
	Operating temperatures:	Min: 15°C, Opt: 25 – 30°C, Max: 40°C
	Surface needs:	100 – 530 m^2 per 1 ton/day
	Water needs:	1'000 L/ton (if initial $MC_{feedstock}$: 80%) 7'000 L/ton (if initial $MC_{feedstock}$: 20%)
	Energy needs[4] :	30 – 55 kWh/ton or none (manual)
	[1]Depends on construction materials; [2] Depends on operation; [3] VS reduction rates range between 50 – 95% depending on feedstock. [4] If Commercial scale, energy needs will depend on machinery used and the demands for electrical installation (see equipment list).	

Suitable biowaste		
	Range of acceptable Moisture:	80 - 95%
	Range of acceptable C:N:	16 - 25
	pH	6.7 – 7.5
	Examples - suitable:	**Examples - unsuitable:**
	- Vegetable waste - Fruit waste - Fish or meat waste - Animal manure	- Garden trimmings - Big chunks of woody materials, coconut shells - Feedstocks with high salt content

Table 10 shows the materials needed in alphabetical order for a small-scale plant (self-use) and a medium/large scale plant (commercial use), as well as the final products and suggested literature for this technology. The essential equipment for a plant to operate is shown in ***bold and italics***;

Table 10: Equipment, products and references for anaerobic digestion

Equipment		
	Small scale (self-use)	**Medium / big scale (commercial)**
	• ***Buckets (for water or waste transport)*** • ***End gas use with valve (stove)*** • ***Gas pipes/Tubes*** • ***Knife/machete*** • *Protection equipment (gloves, face mask, etc.)* • *Record keeping material (monitoring sheets, pens, folders, etc.)* • ***Repair kit*** • *Scale* • *U-bend* • ***Unblocking device (feeding) (Stick)*** • ***Water trap***	• ***Bucket/Water hose*** • *Effluent treatment* • ***End gas use (gas generator or stoves)*** • *Flooring (levelling)* • *Flow meter* • ***Gas pipes/Tubes*** • *Manometer* • *Office construction (office furniture, toilets, showers, etc.)* • *pH meter* • *Protection equipment (gloves, face mask, etc.)* • ***Reactor (different types)*** • ***Record keeping material (monitoring sheets, pens, folders, etc.)*** • ***Repair kit*** • ***Scale*** • *Skid loader/Shovel or Fork* • ***Shredder + spare parts*** • ***Unblocking device (feeding) (Stick)*** • ***Valves*** • ***Water trap*** • ***Wheel barrow/Bucket***
	Materials for digester types (both small, medium and big scale) • Fixed-dome digester: ***Construction material (concrete, bricks, etc.)*** • Floating-drum digester: ***Reactor (different off-the-shelf types)*** • Tubular digester: ***Tubular digester and components***	

Product	
	The main products of anaerobic digestion (AD) are biogas and digestate. The biogas is a combustible gas fuel formed through the conversion of organic carbon in the feedstock into its most reduced form (CH_4) and its most oxidized state (CO_2). Apart from CH_4 (55–60%) and CO_2 (35–40%), biogas also contains several other gaseous "impurities", such as hydrogen sulphide, nitrogen, oxygen and hydrogen. The energy value of biogas derives from the contained methane and shows typical lower heating values (LHV) for biogas of 21–24 MJ/m³ or around 6 kWh/m³ Table 11 shows the biogas yield of several different substrates. Directly burning biogas in stoves is the easiest way of taking advantage of biogas energy. Alternatively, biogas can be used in lamps or converted to electricity in gas generators. The produced slurry (digestate) is rich in nitrogen and can be utilised in agriculture as a nutrient fertilizer and/or organic amendment.

Ref.	
	Vögeli et al. (2014); Lohri et al. (2017)

Table 11: Biogas and methane production (adapted from González-Miranda et al. (2016))

Type	Biogas (NL/kg VS)	CH_4 in biogas (%)	CH_4 (NL/kg VS)
Waste fruits	728	59	401
Waste vegetables	579	60	345
Unsorted organics	503	61	298
Animal leftovers	484	63	312
Waste bread	571	59	291
Fallen leaves	283	61	178
Fresh garden waste	692	60	409
Waste paper	762	60	446
OFMSW	601	60	348

VS: Volatile Solids; NL: normal litter (v as at normal conditions).

The AD process happens in closed, gastight digesters. Digesters range in complexity from simple cylindrical vessels with no moving parts to fully automated industrial facilities. Biogas systems can be classified according to critical operating parameters and elements of digester design. The main distinguishing features are: total solids content (wet/dry systems), feeding mode (continuous/batch), operating temperatures (mesophilic/thermophilic) and number of stages. Figure 10 shows some of the existing digester types.

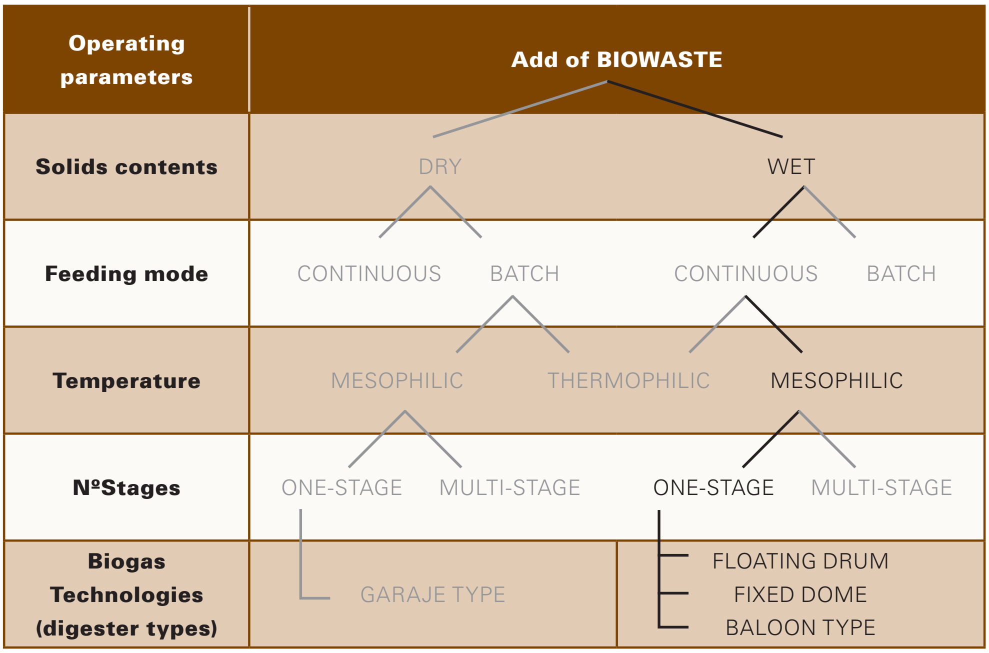

Figure 10: Biogas digester types considered for low- and middle-income settings presented in this manual (in black)

This manual does not cover all design options, but rather focuses on those that are considered appropriate for low- and middle-income settings and for a biowaste feedstock. The three main types of digesters considered are: the fixed-dome digester, the floating-drum digester and the tubular digester, all of which are wet digestion systems operated in continuous mode under mesophilic conditions (Vögeli et al., 2014).

FIXED DOME DIGESTER

Figure 11: Fixed-dome digester under construction in Lesotho

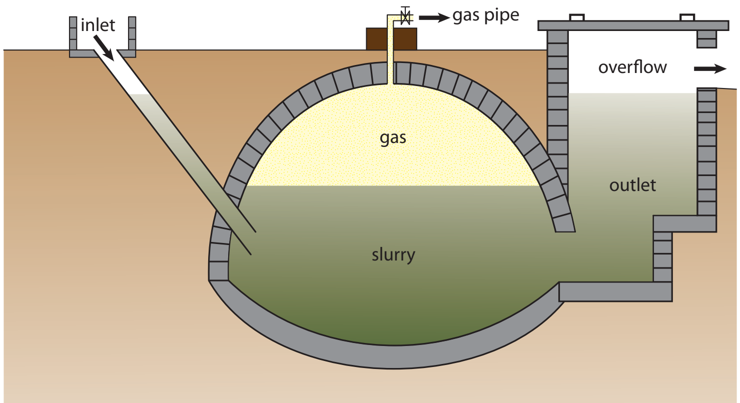

Figure 12: Scheme of fixed-dome digester

Description

A fixed-dome plant is comprised of a closed dome shape digester with an immovable, rigid gas-holder, a feed stock inlet and a displacement pit, also named the compensation tank. The gas produced in the digester is stored in the upper part of the reactor. With a closed outlet gas valve, increasing gas production elevates the gas pressure inside the digester, thereby pushing the digestate into the compensation tank. When the gas valve is open for gas utilisation, the gas pressure drops and a proportional amount of slurry flows back from the compensation tank into the digester. Typically, such a plant is constructed underground, protecting the digester from low temperatures at night and during cold seasons.

Fixed dome plants are only recommended for situations where experienced biogas technicians with specific technical skills in construction are available to ensure a gas tight construction.

Advantajes & Disadvantages

Advantajes	Disadvantages
• Relative low construction costs • Long life span if well-constructed • Absence of moving parts or corroding metal parts • Underground construction saves space and protects the digester from temperature fluctuation • Provides opportunities for skilled local employment	• Certain specific technical skills are required to ensure a gas-tight construction • Fluctuating gas pressure depending on volume of stored gas • Special sealant is required for the inside plastering of the gasholder (e.g. bee wax – engine oil mixture, acrylic emulsion) • Gas leaks may occur when not constructed by experienced masons • Difficult to construct in bedrock • Difficult to repair once constructed as the reactor is located under soil

FLOATING-DRUM DIGESTER

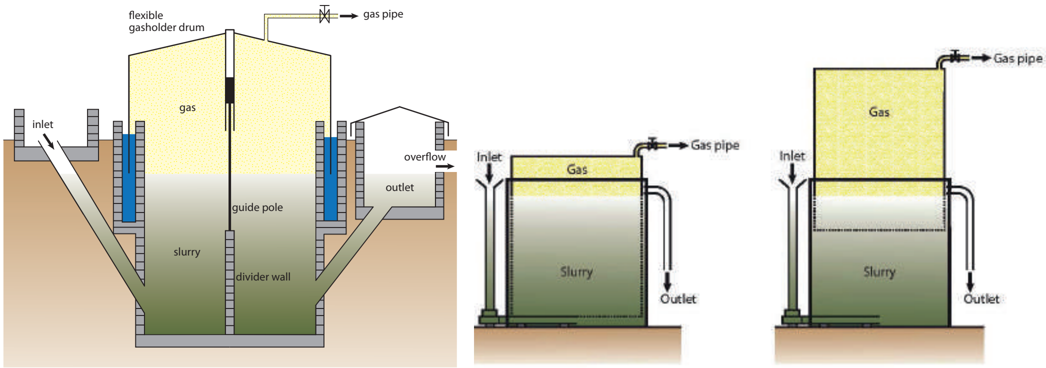

Figure 13: Schemes underground floating drum (left) and above ground drum (right)

Figure 14: Underground floating-drum digester for market waste in India (left) and above ground floating-drum digester for households in India, made of fiberglass reinforced plastic (right)

Description

A floating-drum biogas plant consists of a cylindrical digester and a movable, floating gasholder (drum). The digester is generally constructed underground, whereas the floating gasholder is above ground (see Figure 13 left and Figure 14 left). Smaller household-scale systems may also be fully above ground (see Figure 13 right and Figure 14 right).

The gas produced collects in the gas drum, which rises or falls again, depending on the amount of gas produced and used. The drum level provides a useful visual indicator of the quantity of gas available. The gas is provided at a relatively constant pressure, which depends on the weight of the drum. To increase gas pressure, additional weights can be added on top of the gasholder. The gasholder floats either directly on the fermenting slurry or in a specifically constructed separate water jacket that reduces methane leakage as shown in Figure 13. The design size of floating-drum plants is flexible, with digester sizes typically ranging between 1– 50 m^3.

Advantajes & Disadvantages

Advantajes	Disadvantages
• Simple and easy operation • The volume of stored gas is directly visible • Constant gas pressure • Relatively easy construction • Construction errors do not lead to major problems in operation and gas yield	• High material costs for steel drum • Susceptibility of steel parts to corrosion (because of this, floating-drum plants have a shorter life span than fixed-dome plants) • Regular maintenance costs for the painting of the drum (if made of steel) • If fibrous substrates are used, the gasholder shows a tendency to get “stuck” in the scum layer (if gasholder floats on slurry)

TUBULAR DIGESTER

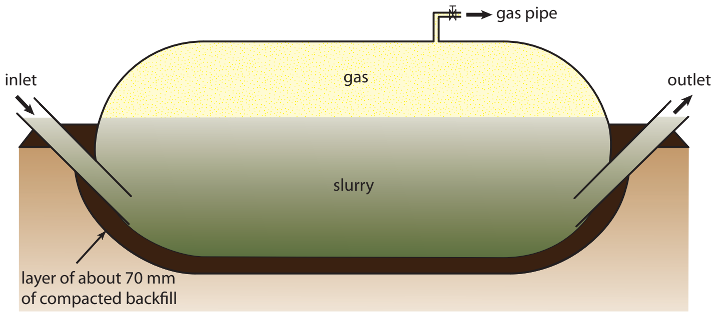

Figure 15: Tubular digester in Costa Rica (left) and scheme of balloon digester (right)

Description

A tubular biogas plant consists of a sausage shaped, heat-sealed, weather resistant plastic or rubber bag (balloon) that serves as digester and gas holder in one. The gas is stored in the upper part of the balloon. The inlet and outlet are attached directly to the balloon. As a result of the shape, no short-circuiting occurs, but since tubular digesters typically have no stirring device, active mixing is limited and digestate flows through the reactor in a plug-flow manner. Placing weights on the balloon while taking care not to damage it can increase gas pressure.

The benefit of these digesters is that they can be constructed at low cost by standardised prefabrication. Additionally, they are suitable for use in areas with a high groundwater table. However, the plastic balloon is quite fragile and susceptible to mechanical damage and has a relatively short life span of two to five years. To avoid damage to, and deterioration of the balloon, it is important to protect the bag from direct solar radiation with a roof. Additionally, a wire-mesh fence will help to protect against damage by animals.

Advantajes & Disadvantages

Advantajes	Disadvantages
• Low construction cost • Ease of transportation • Easy to construct • High digester temperatures in warm climates • Uncomplicated emptying and maintenance • Shallow installation depth suitable for use in areas with a high groundwater table or hard bedrock	• Relative short lifespan • Susceptible to mechanical damage • Material usually not available locally • Low gas pressure requires extra weights • Scum cannot be removed from digester • Local craftsmen are rarely in a position to repair a damaged balloon

BLACK SOLDIER FLY (BSF) PROCESSING

Black soldier fly (BSF) processing is an emerging technology in organic waste treatment. It involves the use of the larvae of the Black Soldier Fly (BSF), *Hermetia illucens*, to biologically transform the biowaste into insect larvae biomass and a treated organic waste residue. Larvae consist of ±35% protein and ±30% crude fat. This insect protein is a potential feed resource for chicken and fish farmers.

The BSF larvae feed on biowaste and develop until the stage of pupation, and are harvested before pupation. Under controlled conditions (28 °C, 75% relative humidity), the total development from egg to adult lasts 20–35 days. As a fly, they survive for one week, during which they focus on reproducing. As a fly, they do not eat and, therefore, also do not transmit diseases.

Waste reduction of up to 80% (on a wet weight basis) has been demonstrated. The residue, a substance similar to compost, contains nutrients and organic matter. Furthermore, a high waste-to-biomass conversion rate of up to 25% (on wet weight basis) is possible. There is no need for sophisticated high-end technology to operate such a facility and it is, therefore, suitable for low- and middle-income settings.

Table 12: Technical considerations and suitable biowaste for BSF

Technical consideration		
	Lifetime installation[1]:	10 years
	Processing time:	14 days (lifecycle of the larvae)
	Mass reduction:	50 – 80%
	Labour (n° of operators):	3 (<1 ton/day) • 1 – 2 operators per additional ton/day • 1 additional worker every 5 tons
	Operating temperatures:	15 - 47°C, Optimal: 28 - 32°C
	Surface needs:	50 m² for nursery and 100 m² per 1 ton/day for waste treatment area
	Water needs:	200 L/ton (if initial $MC_{feedstock}$: 70%) 2'200 L/ton (if initial $MC_{feedstock}$: 20%)
	Energy needs[2]:	90 – 105 kWh/ton or none (manual)
	[1] Depends on construction materials; [2] If Commercial scale, energy needs will depend on machinery used and the demands for electrical installation (see r equipment list).	

Suitable biowaste		
	Range of acceptable Moisture:	70 – 80%
	Range of acceptable C:N:	Non influential
	pH	4.5 – 8.9
	Examples - suitable:	**Examples - unsuitable:**
	- Vegetable waste - Fruit waste - Fish or meat waste - Animal manure	- Big chunks of woody materials, coconut shells

Figure 16

Table 13 shows the materials needed in alphabetical order for a small scale plant (self-use) and a medium/large scale plant (commercial use), as well as the final products and suggested literature for this technology. The essential equipment for a plant to operate is shown in ***bold and italics.***

Table 13: Equipment, products and references for BSF

	Small scale (self-use)	Medium / big scale (commercial)	
Equipment	• ***Ant traps*** • *Bags* • *Bedding material* • ***Containers with lids*** • ***Knife/machete*** • ***Larvae*** • *Oviposition material (cardboard)* • *Protection equipment (gloves, face mask, etc.)* • *Record keeping material (monitoring sheets, pens, folders, etc.)* • *Scale* • ***Shovel/Fork*** • ***Wheel barrow/ Bucket***	• ***Ant trap*** • *Bagging machine + Spare parts* • ***Bags*** • ***Bedding material*** • ***Buckets*** • ***Containers*** • *Cotton cloth* • *Flooring (concrete, with leachate collection)* • *Fridge* • *Gas stove* • *Generator + Spare parts* • *High pressure water* • *Hose* • ***Larvae*** • ***Light*** • *Metal frames/bars* • ***Nets (love and dark cage)*** • *Office construction (office furniture, toilets, showers)*	• ***Oviposition material*** • *Pallet trolley* • *Pallets* • *Protection equipment (gloves, face mask, etc.)* • ***Record keeping material (monitoring sheets, pens, folders, etc.)*** • ***Roofing (closed room)*** • ***Scale*** • ***Skid loader/Shovel or Fork*** • ***Shredder + Spare parts*** • ***Sieve*** • *Stick* • *Tweezers* • ***Washing machine facility*** • ***Wheel barrow/ Bucket /small truck (+spare parts)***

Product

The main products resulting from the BSF technology are the larvae and the residue. The harvested prepupae contain 40% protein and 30% fat. The grown larvae can be used as a (partial) replacement for fish meal in animal feed as defatted insect meal contains a similar protein and amino-acid profile to fishmeal. Other possible products to be explored are the production of biodiesel from larvae or the use of the chitin and the oil.

The residue, on the other hand, still contains valuable nutrients and might be used as a soil amendment. However, due to the short processing time, the residue needs to undergo a maturation phase in order to prevent oxygen depletion in the soil which inhibits seed germination or suppresses root and plant growth.

Figure 17

Ref.

Diener et al. (2011) ; Dortmans (2015) ; Lohri et al. (2017) ; Dortmans et al. (2017)

SLOW PYROLYSIS

Figure 18: Continuous slow pyrolysis system, Vietnam (photo: Ökozentrum, Sofies) – (left) and ARTI style drum (photo: Dan Sweeney) (right)

The thermochemical process called slow pyrolysis or carbonisation entails the decomposition of organic material at high temperatures (300-600°C) in the absence of oxygen. This process lasts from hours to days and results in the production of solid (char), liquid (bio-oil) and gaseous products.

It is generally accepted that the process parameters that most influence product distribution are temperature, heating rate, residence time, and reactor pressure. Particle size, shape and physical properties (ash content, density, moisture content, etc.), and the chemical composition of the biomass, which is composed of three main polymers (i.e. cellulose, hemicelluloses and lignin), also play an important role (Lohri et al. 2016). In small reactors, the process is endothermic and requires an external heating source. This energy can be supplied by combusting part of the material in the reactor (autothermal systems) or from the outside (indirect heating). Reactors are also classified depending on whether they recirculate and combust the pyrolysis gases internally (retort kilns) or not (non-retort kilns).

Figure 19

Table 14: Technical considerations and suitable biowaste for slow pyrolysis

Technical consideration		
	Lifetime installation[1]:	10 years
	Processing time[2]:	Hours to days
	Mass reduction[3]:	65 – 75%
	Labour (n° of operators):	3 - 5 (<1 ton/day), more installations when > 1 ton/day
	Operating temperatures:	>0°C, the warmer, the better
	Surface needs:	30 - 50 m^2 per 1 ton/day
	Water needs:	5 L /ton
	Energy needs[4] :	300 - 900 kWh/ton
	[1] Depends on construction materials; [2] Depends on operation; [3] The maximum treatment capacity of the slow pyrolysis technologies studied ranged between 240 and 550 kg of feedstock per day; [4] If Commercial scale, energy needs will depend on machinery used and the demands for electrical installation (see r equipment list).	

Suitable biowaste		
	Range of acceptable Moisture:	10 - 15%
	Range of acceptable C:N:	Non influential
	pH	Non influential
	Examples - suitable:	**Examples - unsuitable:**
	- Dry, unmixed, homogeneous, uncontaminated substrate, preferably with high carbon and low ash content. For example: - Woody or fibrous materials - Cardboard and paper	- Vegetable waste - Fruit waste - Animal manure - Fish & meat waste

Table 15 shows the materials needed in a small scale plant (self-use) and a medium/large scale plant (commercial use), as well as the final products and suggested literature. The essential equipment for a plant to operate is shown in ***bold and italics***. The rest is additional equipment.

Table 15: Equipment, products and references for slow pyrolysis

Equipment	Small scale (self-use)	Medium / big scale (commercial)
	• *Bags* • ***Building material for furnace, reactor and chimney: bricks, cement, metal sheets, metal bars*** • ***Burners (depends on model)*** • ***Fuel (depending on technology)*** • ***Knife/machete*** • ***Oil barrels*** • *Protection equipment (heat-gloves, face mask, etc.)* • *Record keeping material (monitoring sheets, pens, folders, etc.)* • *Scale* • *Shovel/Fork* • *Thermocouples* • ***Wheel barrow/metal bucket***	• *Bagging machine* • ***Bags*** • ***Building material for furnace, reactor and chimney: bricks, cement, metal sheets, metal bars*** • ***Burners (depends on model)*** • ***Fuel (depending on technology)*** • *Generator* • ***Lambda sensor*** • *Office construction (office furniture, toilets, showers, etc.)* • ***Oil barrels*** • ***Pulveriser*** • *Protection equipment (heat-gloves, face mask, etc.)* • ***Record keeping material (monitoring sheets, pens, folders, etc.)*** • *Scale* • *Skid loader / Shovel or Fork* • ***Shredder + Spare parts*** • ***Thermocouples*** • ***Wheel barrow/metal bucket***

Product	
	The relative amounts of the main products of pyrolysis, char (the black, solid residue), bio-oil (the brown vapour condensate), and syngas (the non-condensable vapour), depend on several factors including the heating rate, peak temperature and residence time. Approximate percentages are 35% char, 30% bio-oil and 35% syngas. The char can be briquetted and used as fuel, or used as a soil amendment in combination with nutrient rich materials (e.g. urea, compost, manure, etc.). The energy content of char-dust is around 22–29 MJ/kg (lower than wood charcoal: 31–33 MJ/kg). The major composition of bio-oils are organic acids, esters, alcohols, ketones, phenols, aldehydes, alkenes, furfurals, sugars and some inorganic. They have significant heating values (13-18 MJ/kg), and they can be converted into valuable chemicals, fuels, and distillates for use in engines and turbines for power generation. The syngas or pyrolysis gas, contains carbon dioxide, carbon monoxide, methane, hydrogen, ethane, ethylene, minor amounts of higher gaseous organics and water vapour. The typical low heating values of the pyrolytic gases range between 10 and 20 MJ/Nm^3. This gas is combustible and can be used to supply additional heat to the process.

Ref.	
	Pfyffer (2016); Lohri et al. (2017)

Figure 20: Char briquettes (top), wood based charcoal (bottom-left), char dust (bottom-right)

		Windrow Composting	In-Vessel (and Bin) Composting	Vermicomposting
				
		- Microbiological process through which organic materials are degraded and stabilised into compost. - This process occurs as a result of microbial activity under aerobic conditions (with oxygen). - Biodegradable waste is piled up in long heaps (windrows) where the material is degraded. - Heaps need to be turned in order to improve porosity and supply oxygen	- Microbiological process through which organic materials are degraded and stabilised into compost in rotating vessels. - This process occurs as a result of microbial activity under aerobic conditions (with oxygen). - Organic waste is introduced into rotating vessels, in which conditions (e.g. HR, Temp., etc.) can be kept stable. This accelerates the composting process.	- Biological process through which organic materials are degraded and stabilised by the interaction of microorganisms and earthworms under aerobic conditions (with oxygen) into vermicompost. - Surface worms are suitable for this technology, such as *Eisenia fetida* and *Lumbricus rubellus*. - The complete life cycle of *E. fetida* lasts 70 days.
Technical aspects	**Lifetime installation**	15 – 30 years	15 – 30 years	15 – 30 years
	Processing time	3- 6 months	2 – 3 month	1.5 - 2.5 months
	Mass reduction	35 – 40%	35 – 50%	40 – 80%
	Labour (n° of operators)	- 1 – 2 (<1 ton/day) - 1 – 2.5 (> 1 ton/day)	- 1 (<1 ton/day) - 1 – 2 (> 1 ton/day)	- 1 – 2 (<1 ton/day) - 1 – 2 (> 1 ton/day)
	Operating temp[1]	- Min: >0°C (big piles) - Min: >15°C (small piles)	- Min.: >0°C (big vessels) or >15°C (small vessels) (non-heated vessels) - Min: non-influential (heated vessels)	- Min: 15°C - Optimal: 20 – 25°C - Max: 35°C
	Surface needs	180 - 300 m^2 per ton/day	85 m^2 per ton/day	300 – 580 m^2 per ton/day
	Water needs	5 – 100 L/ton	5 – 60 L/ton	5 – 40 L/ton
	Energy needs	30 – 55 kWh/ton or none (manual)	165 – 190 kWh/ton or none (manual)	30 – 55 kWh/ton or none (manual)
Suitable Biowaste	**Accept. moisture** **Accept. C:N** **pH**	Coarse: 70 – 75%; Fine: 55 – 65% 20 – 50 5.5 – 7.5	Coarse: 70-75%; Fine: 55 – 65% 20 – 50 5.5 – 7.5	70 – 90% 15 – 25 Acceptable 4.5 – 9, Optimum: 7.5 – 8
	Examples	- Garden trimming - Vegetable waste - Fruit waste - Fish or meat waste - Animal manure	- Garden trimming - Vegetable waste - Fruit waste - Fish or meat waste - Animal manure	- Vegetable waste - Fruit waste - Animal manure - OFMSW
	End Products & Use	- Compost is a stable, dark brown, soil like material that improves soil structure and increases the nutrients availability in the soil. - Besides compost, other outputs produced are leachate, water vapour and CO_2.	- Compost is a stable, dark brown, soil like material that improves soil structure and increases the nutrient availability in the soil. - Besides compost, other outputs produced are leachate, water vapour and CO_2.	- Vermicompost is a stable, dark-brown, granular, soil-like material that has shown to have higher levels of nutrients than compost. - Leachate (worm-tea) from the worm bins can also be used as fertiliser - The worms are rich in protein and can be used as animal feed.

Anaerobic digestion	Black soldier fly (BSF) processing	Slow pyrolysis
		 
- Microbiological process through which organic materials are decomposed while generating a fuel gas (biogas) and nutrient -rich digestate. - This process occurs as a result of microbial activity under anaerobic conditions (without oxygen) in airproof reactors called digesters. - 3 types of digesters considered in the manual. All are one-stage, wet, continuous and mesophilic	- Biological process using larvae of BSF to transform organic waste into insect fat and protein. - Result of larvae of BSF actions under aerobic condition (with oxygen). - The BSF feed on the biowaste and develop through 6 larval instars. They are harvested in their last larval stage when they crawl out of the moist feed source in search for a dry pupation site.	- Thermochemical process which transforms organic materials into char, liquid and gas. - Result of heating (300-600°C) under anaerobic conditions (without O_2). - Relative proportion between end-products depends on the characteristics of the waste, pyrolyser design and operating parameters (heating rate, final temperature, residence time, etc.).
2 – 20 years (depending type of digester)[2]	10 years	10 years
10 - 40 days	14 days (lifecycle of the larvae)	Hours to days
0 – 20% (depends if water is considered)	- 50 – 80% - Waste to biomass conversion 25%	65 – 75%
- 1 (<1 ton/day) - 1 – 2 (> 1 ton/day)	3 (<1 ton/day) and: - 1 – 2 workers per additional ton/day - 1 additional worker every 5 tons	- 3-5 (<1 ton/day) - if (> 1 ton/day): more installations
- Min: 15°C - Optimal: 25 – 30°C - Max: 40°C	- Adequate: 15 – 47°C - Optimal: 28 – 32°C	- Min: >0°C - The warmer, the better
100 – 530 m² per ton/day	50 m² for nursery and 100 m² per ton/day	30 – 50 m²/ton*day
Check input MC required	Check input MC required	No water needs
30 – 55 kWh/ton or none (manual)	90 – 105 kWh/ton or none (manual)	300 – 900 kWh/ton (if indirectly heated)
80 – 95% 16 – 25 6 – 7.5	70 – 80% Non influential 4.5 – 8.9	10 – 15% Non influential Non influential
- Vegetable waste - Fruit waste - Fish or meat waste - Animal manure	- Vegetable waste - Fruit waste - Fish or meat waste - Animal manure	- Dry unmixed, homogeneous, uncontaminated substrate, preferably with high carbon and low ash content, e.g.: woody materials, coconut shells and meat
- Biogas is a combustible gas fuel, composed of CH_4 (55–60%), CO_2 (35–40%) and "impurities", such as hydrogen sulphide, nitrogen, oxygen and hydrogen. - The digestate is rich in nitrogen and can be utilised in agriculture as a nutrient fertiliser or organic amendment.	- Larvae: the harvested prepupae contain 40% crude protein and 30% fat and residues. The grown larvae are suitable as a (partial) replacement of fish meal in animal feed - The residue still contains valuable nutrients and might be used as a soil amendment after a maturation phase (composting).	- The char can later be briquetted and used as fuel (22–29 MJ/kg), or used as a soil amendment. - Bio-oils have significant heating values (13-18 MJ/kg), and can be converted into valuable chemicals and fuels. - The syngas (10 - 20 MJ/Nm³) is a flammable gas and can be used to supply additional heat to the process.

[1]Operating temp.: shows the minimum, optimum and maximum possible ambient temperatures for the treatment technology to operate.
[2]Fixed-dome: 15-20; Floating-dome: 3 -5 (humid climate), 8 – 12 (dry climate); Tubular: 2 -

Table 16: Comparative overview of the biowaste treatment technologies

SOWATT
Step by Step

In this second part, we shall dive into the core of the decision process, following the nine Steps shown below.

Step 1 : What is your problem? – Framing the problem
This first Step will help you frame the problem and define the focus area, as well as amounts and characteristics of waste to consider.

Step 2 : Who should you involve? – Stakeholder analysis
This Step explains which stakeholders should be included in the decision making process.

Step 3: Which technologies should you consider? – Identifying alternatives
This Step presents the technology alternatives and explains how to add new ones if required.

Step 4 : How do you choose among different treatment technologies? – Objective and attribute validation
This Step presents an objective hierarchy, defines how to validate these objectives and explains how to add new objectives if required.

Step 5 : How do the technologies perform for each objective? – Performance estimation
This Step details how to estimate the performance of each technology with regard to each objective.

Step 6 : What is the relative importance between objectives? – Workshops to elicit preferences
This Step presents a method for determining weights and preferences for the different objectives, taking into account the local context and stakeholders.

Step 7: Data analysis
This Step introduces the calculations required to analyse the results and show the final comparison.

Step 8: Displaying and interpreting results
This Step indicates which chart types are adequate to convey all the information, as well as how to interpret them.

Step 9: Final discussion
This final Step introduces some aspects to take into consideration when presenting the results to local stakeholders.

STEP 1:
What is your problem? Framing the problem

Step 1

For every decision problem, setting clear system boundaries is a very important first Step, both in time and space. This Step highlights key questions that need answering before you start. Contents of this chapter:

This chapter explains why these questions are important:

- For which area do you want to provide a biowaste treatment technology?
- How much biowaste and what type of biowaste is generated in this area and what is your time unit (per day, week, month or year)?
- Are you considering one treatment type and facility for this area, or shall the area be subdivided into smaller spatial units (divisions, wards, neighbourhoods, housing complexes, etc.) where different treatment types might be implemented?

Answering these questions will help specify the scope of the problem. Clear answers to these questions are important as this will determine the waste types and amounts that you will be dealing with and this will influence the technology choice and scale.

DEFINING YOUR FOCUS AREA

Selecting the spatial area for which you want to choose the biowaste treatment technology is the very first Step. Even if you cannot define the exact spatial area you want to cover, it is advisable to develop at least a vague idea. Here are some examples:

You are a member of a neighbourhood council in a medium size city. You choose your neighbourhood as the target area of	You are a municipal officer responsible for waste management of a city. You consider the entire city as your area of intervention.	You are an operator or manager of a landfill, and you are interested in choosing a technology to process biowaste arriving to the landfill.

Other examples could be given and there is no right or wrong answer to this question. Whatever the answer, it is important to define and document it to avoid disagreements and confusion at a later stage.

GETTING FAMILIAR WITH THE LOCAL WASTE MANAGEMENT SYSTEM

Obtaining a better understanding of the solid waste management (SWM) system in your local setting will help you define your system boundaries more precisely. It will also help identify the stakeholders that you will later consider during Step 2 (Who should you involve?). Finally, it will help you understand that the scope of this manual focuses solely on the "treatment" component of the waste management stream (Figure 21).

This chapter introduces the Integrated Solid Waste Management Framework. This framework (Figure 21) provides a structured approach of looking at a SWM system.

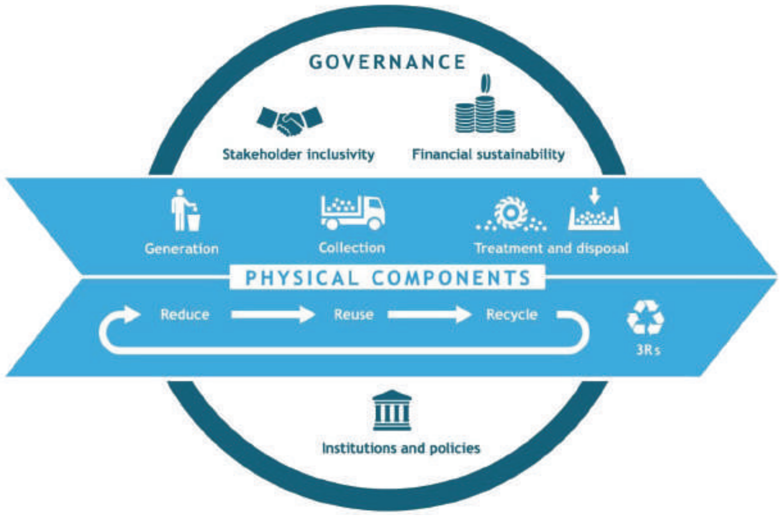

Figure 21: Integrated Solid Waste Management Framework (ISWM) (based on Wilson et al. (2015))

The physical components shown with the blue arrow in Figure 21 include generation, collection, treatment and disposal, as well as 3R (reduce, reuse and recycle). These components are the different processing Steps the waste material passes through.

Furthermore, governance components as shown within the circle in Figure 21 are also essential. These are intangible aspects of waste management, such as stakeholders, financial issues and policies. These overarching components influence the physical components.

This section will pay special attention to waste generation as it defines the "source feedstock" for your biowaste treatment option. The other components will also be briefly introduced, and we encourage you to carefully think about these components in regard to your defined area.

Annex 1 presents an assessment based on this framework for the City of San Fernando (CSF) in La Unión province, Philippines.

KNOWING ABOUT WASTE GENERATION IN THE FOCUS AREA

A precondition to using this manual and starting the process of selection is to know the amounts and types of biowaste in your area. Characterising biowaste with regard to its amount, purity (amount of non-biodegradable content), moisture content, abundance of lingo cellulosic materials, and C:N ratio, is key to understanding which treatment options are technically suitable.

Amounts and characteristics of biowaste in your area may differ depending on the waste generator, but also on the current storage and collection practices. Furthermore, amounts and characteristics may vary during the year.

In your defined spatial area, the questions you will need to answer are:

- Who generates biowaste?
  - Consider different sources, such as:

- Households	- Commerce
- Gardens and parks	- Food processing industries
- Markets	- Beverage industries
- Restaurants	

- How much and what type of biowaste is generated from these sources?
- Is this biowaste source segregated?
- What is the quality of biowaste from these sources (are non-organic substances mixed in with this biowaste)?
- Do the biowaste amounts and characteristics vary during the year from these sources?

This information should then allow you to answer: "Which sources provide how much good quality, source segregated biowaste and where?"

Finding answers to these questions will involve data collection. Data collection campaigns can last between a few days and a month depending on the availability of information. At the end of the data collection phase, you should be able to fill, as much as possible, a similar table to Table 17. Such a table should be filled in for each type of waste generator.

Table 17: Biowaste generation and characterization data required for each type of generator

Type of waste generator:____

Biowaste fractions	Current use/final disposal[1]	Amount[2]	Unit[3]	Variations[4]
Coconut shells				
Coconut meat				
Wood material				
Reed baskets				
Grass clippings				
Vegetable waste				
Fruit waste				
Fish waste				
Meat waste				
Non separated [4] **biowaste**				
Animal manure				
...				

[1] *Describes current treatment/use or final disposal (in amounts and description). This gives insight on the existing practices which might compete with future biowaste treatment plans*
[2] *Specify if the amount given refers to generated amount or collected amount.*
[3] *Do not forget to include the unit of measurement, which always includes a time component (e.g. kg/day, kg/week, tons/day, and tons/week). The values in this column should have the same unit of measurement. Please convert the units of the gathered data into one of the provided options.*
[4] *Variations: how much can the amount of collected waste vary compared to the yearly average (± tons/month compared to the average). Ideally, these values should be provided in the same unit as the previous column.*

Equation 1 indicates how to calculate the total biowaste amount generated by each type of waste generator.

Equation 1

$$W_{total} = N^{o}_{entity} \cdot W_{ent.avg} \cdot Biowaste\ ratio \cdot Collection\ factor$$

Where:

- W_{total}: total waste generated
- N^{o}_{entity}: Number of entities
- $W_{ent.avg}$: Average generation of waste per entity

The classification provided in Table 17 is a mere suggestion; please adapt it for your case study if required. Table 18 numbers a list of information that can be gathered during the data collection phase.

Table 18: Data needed from each type of biowaste generator

Type of waste generator		Data needed
Municipal waste	**Households**	Number of inhabitants and households Waste amounts per capita Waste characterisation (what percentage is biowaste?) Waste collection coverage Yearly variability of biowaste amounts
Municipal waste	**Market**	Number of fruit/vegetable/fish/ meat stalls Waste amounts per stalls/market Waste characterisation (how much is biowaste?) Waste collection coverage Yearly variability of biowaste amounts
Municipal waste	**Garden and park**	Number of gardens and parks in the focus area Biowaste amounts per garden and park Waste characterisation (how much is biowaste?) Waste collection coverage Yearly variability of biowaste amounts
Municipal waste	**Restaurant**	Number of restaurants in the focus area Waste amounts per restaurant Waste characterisation (how much is biowaste?) Waste collection coverage Yearly variability of biowaste amounts
Municipal waste	**Retail premises**	Number of retail premises/shops Waste amounts per retail premises/shops Waste characterisation (how much is biowaste?) Waste collection coverage Yearly variability of biowaste amounts
Industrial waste	**Food processing Beverage processing**	Number of industries Waste amounts per industry Waste characterisation (how much is biowaste?) Waste collection coverage Yearly variability of biowaste amounts

You will realize that data is often scarce. More often than expected, particularly in low income settings, already getting the total population might be a challenge! Consequently, it is normal to make assumptions or to use values from nearby cities or neighbourhoods with similar characteristics.

In the coming pages, three different methods for collecting this information are provided:

- Reviewing existing literature on waste generation (secondary data source)
- Interviewing different waste generators (primary data source)
- Measurement and characterisation of generated mixed waste (primary data source)

SECONDARY DATA SOURCES

Collecting and analysing new data can be quite time and resource consuming. Therefore, before engaging in new studies of waste generation or characterisation, we suggest to start collecting, comparing and analysing existing data contained in previous reports, studies and other sources. Ideally, such information is already available for the spatial area you have defined. Second best is to obtain data from nearby areas with similar settlement and income characteristics, as best estimates.

Examples of stakeholders that might be able to provide existing information are listed below.

- **Solid waste department of the city:** if such a department exists, it might have studies or monitoring results of waste amounts collected, as well as waste characteristics.
- **Company in charge of waste collection:** it might have information on the number of truck loads and/or number of truck trips made per day.
- **Vegetable market agencies/associations:** they might know the amounts of waste generated and collected at markets.
- **Neighbourhood initiatives dedicated to waste management:** they might have neighbourhood information on waste amounts, waste collection practices and local recycling practices.
- **Private or public operators of the landfill:** they might measure incoming trucks and their weight.
- **NGOs active in the city with a waste management interest:** they might have overall city studies or information on specific waste sources and management practices.
- **Municipality:** as a public entity they might have overall city studies, as well as solid waste management budget.
- **Informal recycling sector associations:** they might have information on recycling practices, amounts and number of recyclers or recycling and treatment centres.
- **Operators and managers of biowaste treatment installations:** they might have information on amounts treated and sold.

Identify and contact individuals from these stakeholder groups and arrange meetings with them. They can help you to obtain relevant waste information and may even help to identify other relevant stakeholders whom you should also consider. In all cases, keep in mind the following:

- How reliable is the source of your information?
- Were measurements or estimates made at the point of disposal or at collection? Describe how you estimated the amounts generated.
- Are there seasonal variations regarding waste generation?

PRIMARY DATA SOURCES

If existing data is scarce, old (from more than 10 years ago, or in a fast growing city 5 years), or considered unreliable, then we recommend you conduct one or both of the following activities:

1) Interview waste generators

Estimates of waste amounts can be obtained from interviews with stakeholders involved in SWM or the waste generators themselves. Prepare your interview questions based on the information required (Table 17 and Table 18) and remember to check the information collected for consistency and quality by comparing with references and answers from other interviews.

Be sure that the term "biowaste" is clearly defined to the interviewee to avoid misunderstanding. If you are asking about waste amounts in a household, do not forget to ask the number of household members so that you can calculate a per capita amount generated.

In order to calculate the amount of biowaste generated, the following questions might be helpful to ask in an interview:

- How many bins/buckets of waste are you producing per day/week?
- What is the size of your waste bin/bucket (litre or volume)?
- Is there any week/month when you fill up more bins/buckets of waste compared to the average amount? If yes, when does this happen and how much more is it than usual (1.2 times more or 1.5 or 2, etc.)?
- What type of biowaste are you generating (kitchen waste, garden waste, etc.)?
- Are you mixing biowaste with other types of waste (i.e. plastic, glass, metal, etc.)?

2) Measurement and characterisation of generated mixed waste

If interview information does not lead to satisfactory results, then a brief waste sampling and characterisation exercise may be necessary. One method is explained below. Further information can be found in (UNEP, 2009; Waste Concern, 2010; Lenkiewicz, 2017) or in the open online course entitled *"Municipal Solid Waste Management in Developing Countries*" (see videos "Planning a waste generation and characterisation study" and "Conducting a waste generation and characterisation study" on *www.coursera.org/learn/solid-waste-management*)[1] .

Such a sampling and characterisation exercise should be conducted for each type of waste generator separately (i.e. households, markets, restaurants, food processing/beverage industries, etc.).

Material needed for sampling campaign:

- Plastic sheet to cover the ground
- Several buckets or bags for waste separation (approx. volume 20 l)
- Weight scale
- Hand gloves and mask for self-protection

How long should the sampling campaign last?

We recommend taking samples over a period of eight consecutive days to consider variations of waste generation during the week. Samples taken on the first day should be discarded since they might contain waste previously stored in the household.

Ideally, annual variations could be recorded by repeating the sampling campaign twice to four times per year. If not possible, it can also be estimated from information given in interviews with questions, such as:

- Is this week of sampling representative of the year? If not, which months are the most representative of the annual average?

[1] The course "Municipal Solid Waste Management in Developing Countries" is available for free on the learning platform Coursera. The videos of the course are also on YouTube. The links to both platforms are on our webpage *www.eawag.ch/mooc*.

- Is there any month when the waste generation increases or decreases considerably? By how much, when compared to the annual average (1.5x, 2x, etc.)?

How many waste generators should be sampled?
We recommend that you collect and analyse waste from at least 10 generators of each type of waste generator i.e. 10 households, 10 stalls or carts/bin for market waste, 10 restaurants, etc.). Select these 10 sources randomly.

How should the waste for sampling be obtained?
Inform the generator about your measurement campaign; explain the procedure and provide them with one or more receptacles.

On a daily basis, collect the receptacles and again provide empty receptacles, ideally at the same time during the day for seven days.

Measure the weight of the collected waste. Do not forget to subtract the weight of the empty waste receptacle.

How should the daily amount of waste generated be evaluated?
For each type of waste generator: Weigh the total amount of waste collected daily (W_{t_i}). Then, consider how many generators participated in the measurement campaign (N_{t_i}). Calculate the daily waste generation rate per type of waste generator as follows:

Equation 2

$$\textit{Daily waste generation rate}_{\textit{generator}_i} \; (Dwgr_{generator_i}) = \frac{W_{t_i}}{N_{t_i}}$$

Based on how many generators are present in the focus area (N_{tot_i}), the overall amount of waste generated can be estimated.

Equation 3

$$\textit{Daily waste generated}_{\textit{generator}_i} = Dwgr_{generator_i} \cdot N_{tot_i}$$

When should the samples be analysed?
Samples should be analysed within 1 day, otherwise the material might decompose, which will alter its properties.

How should the sample be split?
If your total waste sample is bigger than 200kg, we recommend using the **Quartering technique** to obtain a sample size of around 50kg (see Figure 22). Follow these steps:

- Place a large plastic sheet on the floor and put the waste onto it
- Reduce the large waste pieces to sizes of not more than 15 cm
- Thoroughly mix the waste to a homogeneous pile.
- Divide the waste pile into four quarters using straight lines perpendicular to each other
- Remove two of these quarters to keep half the original pile.
This is your remaining waste.
- Repeat the mixing and quartering again for the remaining waste until you obtain the desired sample size of around 50 kg
- Weigh the new remaining waste sample and proceed to the manual sorting and classification of components as explained below.

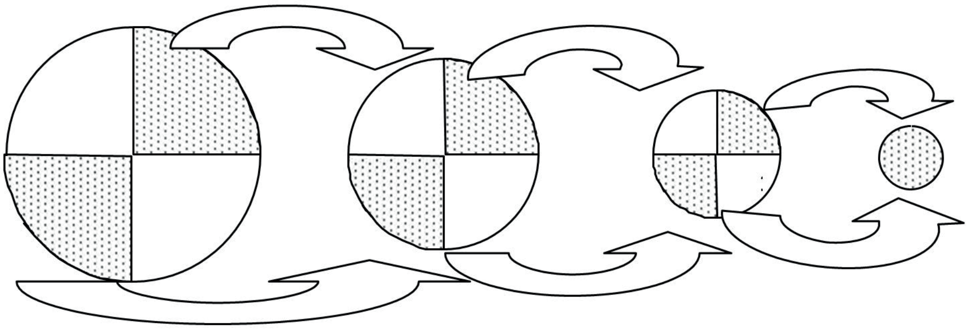

Figure 22: Quartering method

How should the waste fractions be sorted?
The waste sample is now sorted manually into different fractions as the ones shown in Table 19.

Table 19: Type of sorted waste fraction

Sorted waste fraction – biowaste (organic)	Sorted waste fraction - inorganic
Fruit & vegetable residues	Paper
Meat & Fish	Glass
Hard or woody residues	Plastic
Garden trimmings	Metal
Other (check Table 17)	Other

How to calculate the percentage of each waste fraction? – The fractions are sorted into different buckets or plastic bags.

- Weigh the empty buckets or bags before sorting
- Sort the whole waste sample by fractions into the various buckets/bags as shown in Table 19
- After sorting the whole sample, weigh each bucket/bag separately
- From this result, subtract the weight of the empty bucket/bag. With this, you will obtain the weight of each sorted waste fraction (P_i)
- Sum all weights of all sorted waste fractions (sum of P_1-P_n) to obtain the weight of the whole samples (W_t)
- Calculate the percentage of each waste fraction (P_i) by dividing its weight by the whole sample weight (W_t) and multiplying this by 100

Equation 4

$$Percentage_{fraction\ i}\ (\%) = \frac{P_i \cdot 100}{W_t}$$

The values obtained in this section will be referred to again in the manual, especially in Step 5.

KNOWING ABOUT WASTE COLLECTION IN THE FOCUS AREA

Collection is the activity that involves removing the waste from the point of generation and transporting it to some other location: a transfer station, a treatment plant or a disposal facility. Collection is often the most budget-intensive activity among all waste related activities for a municipality. If collection is two-tiered, then we distinguish primary collection (from waste generator to collection/transfer point) and secondary collection (from collection/transfer point to treatment or disposal).

Primary collection infrastructure is often simple and low-tech; most of the time it is driven by human or animal force. Some examples are presented in Figure 23 and Figure 24. Secondary collection uses bigger vehicles, which can travel longer distances (Figure 24 right). At transfer station is where waste is loaded from primary collection vehicles into secondary collection vehicles (Figure 24 left). Dispersed smaller amounts of biowaste are more challenging to manage than larger amounts at fewer locations, which are more efficient and cost effective to work with.

Figure 23: Primary collection in Vietnam (Left) - Primary collection in India (Right)

Figure 24: Transfer station in Indonesia (Left) - Secondary collection in Vietnam (Right)

Knowing about waste collection in the focus area involves knowing the answers to the questions below. With regard to biowaste, you will want to identify sources and collection systems specific to biowaste.

- Who collects the waste from the different type of waste generators and where does it go to?
- How often is waste collected?
- What kinds of vehicles are used for waste collection?
- How much of the generated waste is collected (collection coverage), and what happens to the uncollected waste?
- Pay special attention to the biowaste fraction. If source segregation is practised and collection is specific to biowaste, then answer the above questions for biowaste.
- Where are the main generators and sources of biowaste?
- Where does this waste accumulate and how is it collected?

KNOWING ABOUT WASTE TREATMENT IN THE FOCUS AREA

Waste treatment may follow different priorities:

a) Neutralisation/stabilisation: sets a main priority on treating waste so that negative environmental and health impacts are minimised.
b) Valorisation: sets a main priority on treating waste materials to obtain waste-derived products of value.

Many examples of creating value from waste treatment exist. This manual presents several technologies for biowaste treatment, namely: composting, vermicomposting, anaerobic digestion, pyrolysis and black soldier fly treatment (BSF).

Other treatment methods that are applied with mixed waste or other waste fractions (plastic and paper), such as combustion or incineration are not in the scope of this manual. To obtain good knowledge of your local conditions with regard to treatment, you should be able to answer the following questions:

- What kind of treatment is being applied to biowaste in your specific focus area and the larger region?
- Who is responsible for that treatment?
- What are the treatment goals and how successful and for how long have they been operating?

KNOWING ABOUT WASTE DISPOSAL IN THE FOCUS AREA

Disposal is the final step in the solid waste management system. All waste that is not treated nor recycled is disposed. Disposal can be controlled or uncontrolled (see Figure 25 and Figure 26). Controlled waste disposal takes place in landfills, which, depending on the context, are well managed (sanitary landfills) or less (controlled dumping). Uncontrolled dumping refers to illegal or indiscriminate dumping.

To obtain a good understanding of your local conditions with regard to disposal, you should be able to answer the following questions:

- How much of the waste collected is disposed of in controlled landfills?
- Who is responsible for the controlled disposal?
- How much of the waste collected is disposed of in uncontrolled landfills?

Figure 25: Illegal dumping site in Mexico (Left) - Illegal dumping site in Tanzania (Right)

Figure 26: Not well managed landfill in Vietnam (Left) - Well managed sanitary landfill in Colombia (Right)

KNOWING ABOUT WASTE 3R (REDUCE, REUSE, RECYCLE) ACTIVITIES IN YOUR FOCUS AREA

Triple R (3R) activities typically deal with non-biodegradable materials, such as plastics, paper, metals and glass. With regard to biowaste, direct application of waste onto fields and feeding livestock with waste are considered to be reuse practices. Such biowaste reuse practices can be assessed by posing the following questions to the different waste generators:

- How much of your biowaste are you reusing directly by applying it to land or feeding livestock?
- Are you giving part of your biowaste to individuals (farmer, owners of livestock) or companies that reuse your biowaste directly by applying it to land or feeding livestock? If yes, how many bins/buckets of waste is it?
- How much are you paid for supplying this biowaste?

Figure 27: Separated biowaste from a restaurant in Vietnam (Left) - Farmer collecting biowaste in Vietnam (Right)

KNOWING ABOUT WASTE STAKEHOLDERS IN THE FOCUS AREA

The stakeholders are all who are involved in waste management, including those that generate waste. How to identify stakeholders in your focus area and to assess their roles and viewpoints is explained more in detail in Step 2.

KNOWING ABOUT FINANCIAL ISSUES OF WASTE MANAGEMENT IN YOUR FOCUS AREA

It is important to understand how waste management is financed in your focus area. This will also help you identify stakeholders who can influence the system and should be considered in the stakeholder analysis (Step 2). For this, you should be able to answer the following questions:

- For the different waste generators: How much, to whom, and with what frequency do they need to pay for a waste collection service?
- What is the rate of payment compliance?
- What other financial resources are available to cover the costs of waste collection and from whom are they available?
- What is the tipping fee for the collectors at the landfill (fee paid to deliver waste to the landfill)?
- What are the estimated landfill disposal costs (per ton) for the landfill operator?

KNOWING ABOUT INSTITUTIONS AND POLICIES AFFECTING YOUR FOCUS AREA

Existing policies and legislation influence waste management and they might hinder or support the implementation and operation of a biowaste treatment facility. For instance, land use regulations and urban planning strategies may prohibit the construction and operation of waste treatment plants in residential areas. Therefore, being knowledgeable about the following questions on policies and legislation is crucial:

- Do recycling policies exist and how do they affect biowaste treatment?
- Are certain waste treatment technologies specific to biowaste prohibited by law?
- Who owns waste?
- Can waste be accessed and used/recycled by a non-governmental or private entity and what permits and licenses are needed to allow this?

USING ALL INFORMATION TO FRAME YOUR PROBLEM

Now that you have become very knowledgeable about your focus area, you can define and document your problem statement to determine the types of waste and amounts you will be dealing with.

- Which biowaste sources, amounts and characteristics shall be the focus of my biowaste treatment facility?
- When considering biowaste sources, amounts, characteristics and existing collection systems, what would be the scale of the biowaste facility?

Check Annex 1 for a detailed description of the CSF case study.

STEP 2:
Who should you involve? Stakeholder analysis

Now that your problem is framed and you are more familiar with the waste management system of your case area, the next Step is to identify the stakeholders you want to include in the decision making process. This will be the content of this chapter:

In order to do so, this chapter will answer the following questions:

- To whom are we referring when talking about stakeholders?
- Why is it important to consider as many stakeholders as possible?
- How can a stakeholder analysis be conducted?

IDENTIFYING STAKEHOLDERS

Stakeholders are all the people that can influence and/or are affected by the project. The following list gathers examples of stakeholders you might need to take into account, depending on your focus area:

1) Organic waste generators: members of households, market sellers, shopping facilities, food industries, etc.
2) Neighbourhood representatives: cities often are divided into different geographical areas (districts, wards, etc.) which are represented by a representative who, depending on the case, could be elected by those living within the given area
3) Community-level authorities: e.g. community leaders, including religious leaders, who have a large influence within the community
4) Community-based organisations (CBOs): e.g. organisations engaged in self-help activities or in providing affordable services in communities
5) Non-governmental organisations (NGOs): organisations that act as intermediaries between governments and local communities, and are sometimes involved in solid waste service delivery
6) Private/Public service providers: Companies/individuals providing SWM services
7) Informal sector: e.g. waste pickers
8) Municipalities: municipalities have statutory responsibilities for a wide range of SWM service provisions, including operation and maintenance. Different departments of the municipality could act as relevant and independent stakeholders, such as urban development authorities, environmental departments and health and hygiene departments
9) Ministries or departments of ministries: are often involved in SWM management regulations
10) Other

Ideally, all stakeholders that influence the decisions or are affected by a "new" biowaste treatment system should be involved.

ADVANTAGES OF INCLUDING MANY STAKEHOLDERS

At first, it may seem that involving many stakeholders would make the process more complicated and slower as finding a consensus would be more difficult. However, at a second glance, involving more stakeholders in the process and allowing them to participate to achieve consensus is known to strengthen ownership, thereby, increasing acceptance and the sustainability of the outcome.

We strongly recommend including as many stakeholders as possible in the process, especially those having power to influence decisions or who are key to ensuring the long-term sustainability of the biowaste treatment facility.

ITERATIVE APPROACH FOR STAKEHOLDER ANALYSIS

Stakeholder identification and analysis is typically an iterative process where information is obtained through interviews. The following three steps are recommended when conducting a stakeholder analysis:

1. Identify stakeholder groups and develop a stakeholder table
Make a list of stakeholder groups and list individual names and contact information of these stakeholders who you consider will have a stake on the biowaste decision.

2. Assess each stakeholder through interviews
Conduct individual or group interviews in each stakeholder group. Identify and evaluate their role, responsibility and stake in the solid waste management system. Ask questions, such as those listed below (and adapt the questions so that they fit your specific context):

a. What is your role, function and responsibility in waste management?
b. Can you influence the way waste is managed in your city?
c. Who works/ is responsible for the current management?
d. Who do you think would be related to/influenced/affected by waste management in your city?

3. Classify stakeholders into groups
Organise the stakeholders into groups based on criteria, such as: responsibility, profession, or even social attribute (age, gender and income level). Decide which criteria makes most sense for your case study.

When you conduct the interviews, you can ask who additionally could be an interesting stakeholder to approach. With such additional information, the stakeholder list will be updated until no new stakeholders are mentioned.

CSF – CASE STUDY (STEP 2)

In this section, the most important stakeholders identified and involved in the assessment process for the case of CSF will be introduced. A more extensive description of each stakeholder is available in Annex 1.

Waste management services are the responsibility of the City Council and the barangays (smallest administrative division in the Philippines, similar to "ward" or neighbourhood). Within the City Council, there are two departments sharing this responsibility: the Office of the City Environment and Natural Resource Officer (CENRO) and the Office of the City General Services Officer (GSO).

The CENRO is in charge of the technical aspects related to waste management, such as planning, researches/studies, information, education and communication, and assessment. The GSO is in-charge of the logistics part of solid waste management in the city, including collection, street sweeping and managing the sanitary landfill.

Another important stakeholder is the Solid Waste Association of the Philippines (SWAPP), a leading non-profit, multi-sectoral network of solid waste management (SWM) volunteers and practitioners whose aim is to empower local governments, communities, and the private sector towards a clean, safe and sustainable environment. The mission of SWAPP is to build the capacity of Local

Government Units (LGUs), communities, and the private sector to manage solid waste problems in their respective areas through research, training, technical assistance, information exchange, and network building.

Barangays are the smallest administrative and political division and are headed by elected officials. Together, these officials form a council in which one of the members is always a Pollution Control Officer (PCO). The PCOs are responsible for the accomplishment of the environmental ordinances of the municipality. They are also in charge of supervising environmental-related activities occurring within the barangay, which includes waste management (collection, material recovery facility, cleaning and street sweeping, etc.).

Junkshops are private businesses that buy, store and sell recyclable materials to other middlemen. They do some minor processing, such as sorting and pre-cleaning. In CSF, there are 16 accredited junkshops, but there are illegal or unregistered junkshops as well. The City has enacted a Junkshop Ordinance (City Ordinance No. 2004-001), which sets the requirements for the establishment of accredited junkshops in the City.

Table 20 shows the stakeholders identified for the case study in San Fernando City, Philippines. The stakeholders were clustered according to their profession under the assumption that they have similar preferences.

Table 20: Identified Stakeholders and cluster in the case study of CSF

	Position	Cluster		Position	Cluster
1	Head Officer of at CENRO	CENRO	**19**	Former Junkshop manager	Junkshop
2	Officer 1 at CENRO	CENRO	**20**	Junkshop Manager	Junkshop
3	Officer 2 at CENRO	CENRO	**21**	Junkshop operator 1	Junkshop
4	Officer 3 at CENRO	CENRO	**22**	Junkshop operator 2	Junkshop
5	Officer 4 at CENRO	CENRO	**23**	Junkshop operator 3	Junkshop
6	Officer 5 at CENRO	CENRO	**24**	Junkshop operator 4	Junkshop
7	Head Officer of GSO	GSO	**25**	Junkshop operator 5	Junkshop
8	Officer 1 of GSO	GSO	**26**	PCO of B. Catbangen	PCO
9	Officer 2 of GSO	GSO	**27**	PCO of B. Poro	PCO
10	Officer 3 of GSO	GSO	**28**	PCO of B. Barangay 1	PCO
11	Officer 4 of GSO	GSO	**29**	PCO of B. Sibuan-Otong	PCO
12	Landfill and composting plant operator	GSO	**30**	PCO of B. Lingsat	PCO
13	Director of SWAPP (NGO)	NGO	**31**	PCO of B. Saoay	PCO
14	Solid waste management specialist	NGO	**32**	PCO of B. Sevilla	PCO
15	Solid waste management specialist	NGO	**33**	PCO of B. Bangbangolan	PCO
16	Solid waste management specialist	NGO	**34**	PCO of B. Cadaclan	PCO
17	Solid waste management specialist	NGO	**35**	PCO of B. Pao Sur	PCO
18	Solid waste management specialist	NGO	**36**	PCO of B. Cabaroan	PCO
			37	PCO of B. Ilocanos Norte	PCO

CENRO: Cluster of the City Environmental and Natural Resource Office; GSO: Cluster of the City General Service Office; NGO: Cluster of the waste NGO experts; Junkshop: Cluster of a former and a current junkshop manager (informal recycling); PCO: Cluster of the Pollution Control Officers.

STEP 3:
Which technologies should you consider? Identifying alternatives

The next Step is to identify the alternatives for biowaste treatment; in other words, the options that will be considered in the decision problem. These are the contents that will be covered in this chapter.

Step 3

The SOWATT manual considers six treatment options:

1) Windrow composting
2) In-Vessel composting
3) Vermicomposting
4) Anaerobic digestion
5) Slow pyrolysis
6) Black Soldier Fly processing

These technology options cover a wide range of treatment possibilities that are currently considered mature enough to be implemented. However, other technologies could also be added to this list. Also, some of the technologies in the list might not be suitable always.

ARE CERTAIN TECHNOLOGIES NOT FEASIBLE FROM THE ONSET?

The chances of successful implementation of a certain biowaste treatment technology for a specific location can be influenced by different factors (see Figure 28). Examples of such factors are:

- Characteristics of the available biowaste (moisture content, carbon-nitrogen ratio, abundance of lingo cellulosic materials, etc.)
- Legal framework
- Climatic conditions (average temperatures, average relative humidity, etc.)
- Available resources (space, water, electricity, labour, skills, etc.)
- Available financial resources

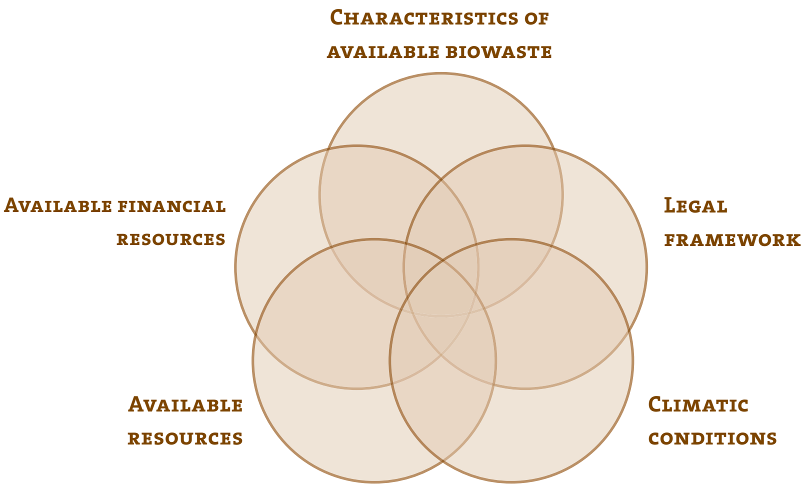

Figure 28: Factors to be considered before applying the SOWATT manual

NATURE OF AVAILABLE BIOWASTE

Some treatment technologies can only process waste with specific characteristics, as summarised in Table 16. For instance, if your available waste consists only of coconut shells (or any other waste with high lignin content), you should not consider anaerobic digestion or BSF-treatment.

If your waste mainly consists of fruit-processing sludge (high moisture content), slow pyrolysis is not a good choice. The nature and characteristics of the available biowaste will, therefore, determine which treatment technologies cannot be used because they are not able to treat such waste. Feedstock characteristics can be partly managed, for instance, by drying the waste to reduce its moisture or by adding additives to it to improve the carbon-nitrogen ratio. However, our experience shows that this is not always feasible and often makes little sense. Therefore, in this manual, the aspect of feedstock characteristics is considered a "discarding" criterion.

So, how can you assess if one of the considered technologies should not be considered based on the nature of your available biowaste?

The following three feedstock characteristics should be considered:

- Moisture content
- Carbon-nitrogen ratio (C:N)
- Presence of coarse lignocellulosic (woody) materials
(e.g. wood, coconut shells, straw, etc.)

Of course, other parameters could be added to the list, such as pH, volatile solid content, protein content, fat content, etc., but these three are sufficient to judge which technology should not be considered (or are not feasible).

Table 21 provides an indication of what are the adequate ranges of each parameter per technology, extracted from Table 16.

Table 21: Acceptable ranges of moisture, C:N and woody material (Lohri et al., 2017)

Parameter	Windrow Composting	In-vessel composting	Vermi-composting	AD	BSF	Slow Pyrolysis
Range of acceptable Moisture	Coarse biowaste: 70 - 75% Fine biowaste: 55 - 65%	Coarse biowaste: 70 - 75% Fine biowaste: 55 - 65%	70 - 90%	80 - 95%	70 - 80%	10 - 15%
Range of acceptable C:N	20 - 50	20 - 50	10 - 25	16 - 25	Non-influential	Non - influential
Coarse woody material content[1]	Inert	Inert	Inert	Inert & risks[2]	Inert	Good feedstock

[1]Coarse woody materials (e.g. branches, coconut-shells, wood pieces, etc.) are inert for all biological processes. Therefore, it does not constitute an adequate feedstock as it will not degrade. For the composting technologies (windrow and in-vessel), it is beneficial to have some coarse material, as it will function as structure giving material. [2]On the contrary, in the case of AD, woody materials are not advisable since they tend to be stored at the bottom of the reactor, which limits the reactor capacity, or on the surface, which blocks the production of biogas.

Based on the available biowaste in your case study and the acceptable ranges per technology shown in Table 21, you can decide whether any of the technologies cannot be used (or are not feasible). Annex 2 provides the moisture content and C:N values for a list of common organic materials.

MOISTURE CONTENT

Moisture content is defined as the weight of water per unit weight of your material, given as a percentage. Here, we present two methods to calculate the moisture content:

a) Oven drying
b) Hand Squeeze test

a) For oven drying, you need the following equipment:

- Oven - 105°C (221°F)
- At least three sampling containers per biowaste (20 x 20 x 5 cm) preferably ceramic or metal (e.g. oven dishes)
- Marked
- Heatproof
- Weighed
- Knife or shredder
- Cutting board
- At least three large bowls
- A scale (0.01 g accuracy resolution)
- Desiccator
- Pen and paper
- Protective equipment (gloves, mask and goggles)

These are the steps to measure moisture content:

1. Weigh the empty small container and record the amount.
2. Add 500 g of feedstock into the container and record the weight. Subtract the weight of the container. This will be the *wet weight*.
3. Introduce the container with the feedstock into an oven and dry it at 110°C during 24 hours.
4. Reweigh the sample and subtract the weight of the container. This is the *dry weight*.
5. Determine the moisture content, using the following equation:

Equation 5

$$Moisture\ content = 100 \cdot \left(\frac{Wet\ weight - Dry\ weight}{Wet\ weight} \right)$$

If the waste is composed of a mix of different feedstocks with different moisture contents, Equation 6 can be used to calculate the overall moisture content of the mix. Provided that feedstock A has a mass of MA and a moisture content of WA, feedstock B has a mass of MB and a moisture content of WB, and feedstock C has a mass of MC and a moisture content of WC, the moisture content of the mix is:

Equation 6

$$Moisture\ content\ of\ mix = \frac{M_A \cdot W_A + M_B \cdot W_B + M_C \cdot W_C}{M_A + M_B + M_C}$$

b) a Hand Squeeze test (from Brewer et al. (2013)) is suitable for fine materials, such as coffee grounds and compost.

Grab a handful of material. Observe your fist while squeezing the material firmly. Release your grip, palm up, and observe the material and your hand. Scan the list of observations in Table 22 and estimate your moisture content.

Table 22: Hand squeeze test – observations and approximate moisture contents

Observation	% Moisture*
Material is crumbly, does not stick together, feels dusty or glove is dry	42 or less
Material feels mostly dry, but has a hint of moisture in it	42 – 47%
Material feels tacky	47 – 52%
Material feels moist	52 – 58%
Material sticks together or glove glistens or has a wet sheen	58 – 63%
Squeezing releases one to two drops of water	63 – 68%
Squeezing releases many drops of water	68 – 73%
Squeezing releases a stream of water or material has a pudding texture	>73

**Fine-textured materials can give accurate estimates. Coarse-textured materials result in low moisture estimates; adjust upwards by as much as 4%.*

With practice, and after confirming your estimates with the oven drying test, your hand becomes "calibrated" and this method is fast and useful.

Further information and a step by step calculation of moisture content can be found in the open online course (see video "Determining moisture content of biowaste mixture" on ***www.coursera.org/learn/solid-waste-management***)[2].

Step 3

CARBON – NITROGEN RATIO

Decomposition of organic materials in your compost pile is greatly increased when you create the proper balance between the carbonaceous materials and the nitrogen-rich materials. Carbon is the basic building block of life for microorganisms, and is a source of energy. Nitrogen is also necessary for proteins, genetic material, and cell structure. This balance is referred to as Carbon-Nitrogen ratio and is shown as C:N.

Annex 2 provides a database of the physical and chemical characteristics (including C:N values) of different organic materials. Providing that you obtained a proper characterisation of your available biowaste, Annex 2 can help you to estimate the C:N ratio of your material.

When the waste consists of a mix of different materials from Annex 2, you can easily calculate the overall C:N. You first need to obtain the information shown in Table 23 for the different fractions to be mixed.

Table 23: How to calculate the C:N of a mix

Fraction	Moisture (%)	$Weight_{wb}$	$\%Carbon_{db}$	$\%Nitrogen_{db}$	C/N Ratio
1	M_1	Q_1	C_1	N_1	C_1/N_1
2	M_2	Q_2	C_2	N_2	C_2/N_2
3	M_3	Q_3	C_3	N_3	C_3/N_3

db: dry basis; wb: wet basis

[2] The online course *"Municipal Solid Waste Management in Developing Countries"* is available for free on the learning platform Coursera. The videos of the course are also on YouTube. Please find links to both platforms on our webpage ***www.eawag.ch/mooc.***

The C:N of the mix will be calculated by the following formula:

Equation 7

$$C{:}N=\frac{Q_1 \cdot C_1 \cdot (100-M_1)+Q_2 \cdot C_2 \cdot (100-M_2)+Q_3 \cdot C_3 \cdot (100-M_3)+...}{Q_1 \cdot N_1 \cdot (100-M_1)+Q_2 \cdot N_2 \cdot (100-M_2)+Q_3 \cdot N_3 \cdot (100-M_3)+...}$$

If you know the nitrogen content for a biowaste, but not the carbon content or the C/N ratio, you can estimate the carbon content based on the volatile solids content if that value is known or can be measured. Volatile Solids (VS) are the components (largely carbon, oxygen, and nitrogen) which burn off an already dry sample in a laboratory furnace at 500-600°C, leaving only the ash (largely calcium, magnesium, phosphorus, potassium, and other mineral elements that do not burn). For most biological materials, the carbon content is between 45 - 60 % of the volatile solids fraction. Assuming 55 % (Adams et al., 1951), the formula to calculate the carbon content is:

Equation 8

$$C\%_{db} = \frac{VS\%_{db}}{1.8}$$

Where:

- *db=dry basis*
- $VS\%_{db}=100-Ash\%_{db}$

If the waste is composed of a mix of different feedstocks with different C:N values, the C:N of the mix needs to be calculated. These values are not provided in this manual and would have to be obtained separately. Equation 9 can be used to compute the C:N of the mix.

	Mass (g or kg)	Moisture (%)	Carbon content ($\%_{db}$)	Nitrogen content ($\%_{db}$)
Feedstock A	M_A	W_A	C_A	N_A
Feedstock B	M_B	W_B	C_B	N_B
Feedstock C	M_C	W_C	C_C	N_C

Equation 9

$$C{:}N \text{ of mix}=\frac{(100-W_A)\cdot M_A \cdot C_A + (100-W_B)\cdot M_B \cdot C_B + (100-W_C)\cdot M_C \cdot C_C}{(100-W_A)\cdot M_A \cdot N_A + (100-W_B)\cdot M_B \cdot N_B + (100-W_C)\cdot M_C \cdot N_C}$$

Further information on carbon nitrogen ratio can be found in the open online course (see video "Calculating C:N ratio of biowaste mixtures" on ***www.coursera.org/learn/solid-waste-management).***

CONTENT OF WOODY MATERIAL

Woody material refers to all hard material that has a high lignocellulosic content. Some examples are: coconut shells, wood chips, barks, sawdust, straw, etc. You do not need to be very precise when determining their content. Observe your biowaste: how much would you estimate is made up of woody or hard materials? Half? Less or more than half? Make a rough estimate and compare it to the values given in Table 21. If the woody content exceeds the limits specified, the technology should not be used (or is not feasible).

LEGAL FRAMEWORK

Several regulations can limit or foster the long-term sustainability of biowaste treatment technologies. They do not impede the construction and operation of a technology per se, but the commercialisation of the final product could be restricted or enhanced by legislation. In many European countries, for instance, compost from non-source-separated biowaste may not be applied in agriculture. This policy has a direct impact on the financial feasibility of private composting plants. Therefore, it is very important to have a look at current legislation in your country/region to make sure you do not face similar restrictions for one or some of the possible end-products considered in your assessment (e.g. compost, vermicompost, gas, animal feed, char, etc.).

Legislation and regulations related to the use and commercialisation of waste-derived products may vary from country to country. Check your specific context by asking the following questions:

- Can the waste derived products be commercialised from a legal perspective?
- Are local or national incentives provided to support the commercialisation of these products (e.g. subsidies)?
- Is the access to and use of biowaste (or certain biowaste types) hindered by legal restrictions?

This information can be obtained by interviewing experts, such as lawyers, NGOs, agricultural or business associations, agricultural research institutes, university departments or even the municipal authorities. Another possibility is to consult legislative documents, such as environmental and agricultural laws, solid waste management rules and regulations, as well as trade laws and regulations.

CLIMATIC CONDITIONS

Some of the technologies considered involve biological processes. Biological processes require a certain temperature and moisture range (Table 16) and, if these conditions cannot be met, the technology would probably fail to function. In the case of low-tech composting facilities in desert-like climates, a facility can dry out quickly. In these types of areas, water is hard to find and its use is often restricted to drinking water or agricultural irrigation. In hot and humid climates (e.g. rainforests), effective moisture control of windrows becomes challenging since water removal from a windrow can only work if there is a gradient in the water saturation of the air. The heavy rainfall in these climates justifies the need for an installation with a roof.

Temperature might be controlled through insulation, heating or cooling processes, whereas moisture can be controlled by a roof (avoid excess moisture by rainfall or excess evaporation) or by adding water. These additional measures will affect investment and operational and maintenance costs to operate the technology. As such climate parameters can typically be controlled despite the costs involved, climate is not considered a “discarding” criterion. Financial consequences are taken into account when assessing economic feasibility (Step 5, section “High economic feasibility”).

AVAILABLE RESOURCES

Certain technologies might be more resource intensive than others. Some technologies require a bigger surface area than others for their installation and land is not always available and may need to be bought or rented. Similarly, some treatment facilities might require constant electricity, or large amounts of water, or several spare parts, or even highly specialised skilled labour.

If the required land is not available and cannot be purchased or rented, only the technologies which can be constructed in the available space can be considered. If land can be purchased or rented, all treatment technologies can be considered. When land needs to be bought or rented, this will have a considerable impact on investment costs, which will affect the economic feasibility of the technologies, as shown in Step 5, section "High economic feasibility".

If the other requirements (electricity supply, water, labor, etc.) cannot be ensured for a technology, its operation will be jeopardised. Missing or limited resources impact technical reliability and economic feasibility. Limited resources will decrease the robustness of the technology and increase the likelihood of technical failure or "non-functional downtime". This is explained more in detail in Step 5, section "High technical reliability". Ensuring the resources are available when required might lead to higher operational costs and, thus, affect the economic feasibility. This aspect of additional costs are further explained in Step 5, section "High economic feasibility". The availability of these resources is, therefore, not considered as a "discarding" criterion as they could be counteracted with higher investment and operating costs.

Finally, the aspect of the skills required for design, construction and operation are crucial preconditions. The existence of a company or organisation that has a track record of successfully building and implementing systems will strengthen the appropriateness of this technology. However, if such a technology at the required scale has never been constructed before in the country, it is worth getting a second expert opinion on the feasibility of local implementation. Again, personnel with the required skills can be hired from somewhere else, which will impact the salary costs.

AVAILABLE FINANCIAL RESOURCES

The existing financial resources, access to loans and/or donations has an important impact on which technologies can be constructed and operated. Low financial capacity acts as a "discarding" criterion.

HOW CAN NEW TECHNOLOGIES BE INCLUDED?

In order to include new technology alternatives in the SOWATT manual, the following approach should be carried out:

1. Describe the treatment technology and how it is operated in detail
2. Evaluate the performance of the treatment technology as explained in Step 5.
3. Validate your results with an expert

Finding experts on a topic is sometimes tricky. Think of who might be familiar with the technology that you are considering adding. You might also find experts on the internet that you could approach by email or a telephone call.

CSF – CASE STUDY (STEP 3)

In the case of CSF, all default technologies in the SOWATT manual were considered. Most of the technologies had already been installed (vermicomposting, slow pyrolysis, AD, etc.), whereas some were completely new (BSF).

STEP 4:
How do you choose among different technologies? Objectives and attributes

At this stage, you should have the following information:

- a well delimited focus area
- a quantified amount of generated biowaste and information about different types of biowaste based on their characteristics,
- a list of stakeholders who you consider relevant,
- the selection of biowaste treatment technologies to consider as alternatives

These are the contents that will be covered in this chapter.

Step 4

In order to select a technology, you should give answers to the following questions:

- Why do you want to build a biowaste treatment technology?
- What should it achieve?
- What are the problems that the installation should remediate?

The answers to these questions will define **the objectives** of your decision problem.

Objectives are the things that matter to decision makers and participants in the decision making process. Without clear objectives, it is not possible to take rational and transparent choices between different alternatives. Objectives are phrased with an adjective or verb that indicates the desired direction of change (e.g. high/low, big/small, increased/decreased, etc.). Once expressed and agreed upon, attributes are defined for the objectives. Attributes define what will be measured to assess how well the objective is achieved. Scoring of a technology is based on how well it achieves the agreed objectives. This information then becomes the basis for comparing technology alternatives.

Example: *Choosing a hotel to stay overnight*

You want to choose a hotel and you have a long list of hotels with available rooms. Before you can make a decision, you first need to define the objectives of what this hotel and room should fulfil. This might be: low noise level, minimum distance to a commercial centre, minimum distance to public transport, low price, highly reliable internet connection in the room, etc. Examples of corresponding possible attributes are average decibels in the room, costs per night and network latency, respectively.

Once you have decided on the objectives, then, you can compare different hotels and check how well they satisfy the objectives you have defined.

Defining the objectives for biowaste treatment will be covered in this chapter. This chapter will include:

- Presentation of "default" objectives and attributes for selecting a biowaste treatment technology
- Conducting a workshop for objective validation
- Generating new objectives (if required)

DEFAULT OBJECTIVES AND ATTRIBUTES

This manual includes a set of objectives that we call "default objectives and sub-objectives", which are arranged in the so-called "Objective hierarchy" (Figure 29). These default objectives were developed in discussion with biowaste treatment experts and decision analysis experts. This set of "default objectives" is what biowaste treatment technologies should generally fulfil in order to ensure their proper operation in the long run.

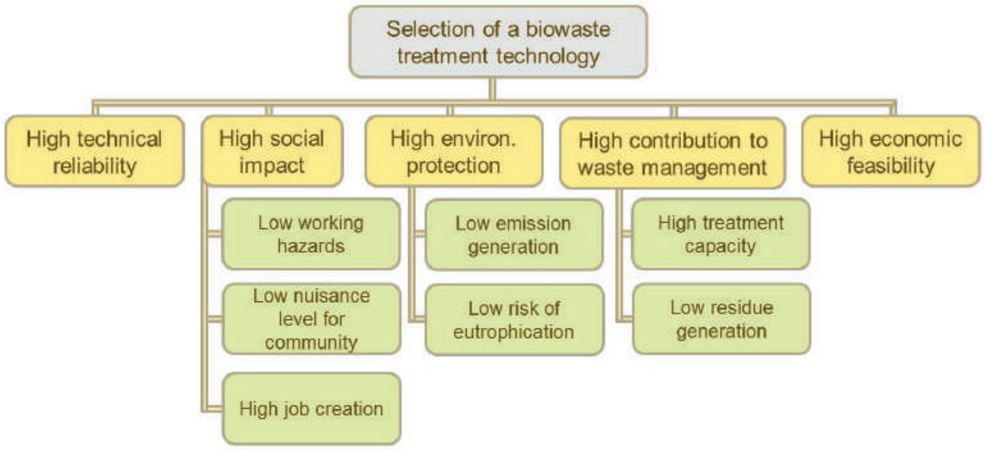

Figure 29: Default objective hierarchy proposed

However, the presented objective hierarchy should not be taken as an unchangeable blueprint, since it might not be valid for every case. Therefore, this manual includes a chapter on how to *validate* if new objectives or sub-objectives need to be added or removed for a given context (see section "Validation of objectives", in Step 4). Such a validation exercise is conducted together with local stakeholders.

There are five main objectives– shown in yellow. Some of these main objectives have several sub-objectives, shown in green. These proposed objectives and sub-objectives can influence expected outcomes, for instance:

- Low generation of emissions and leachate
- Low smell impact
- High contribution to waste management
- High job creation

There are also objectives that relate to the sustainability of the technology, such as:

- High technical reliability
- High social impact on behalf of community
- High economic feasibility

This second set of objectives has often been overlooked in the past, and has sometimes led to the selection of technologies that present operation and maintenance problems over time.

Next, we need to define how the achievement of these objectives can and will be measured.

- How do we measure low risk of eutrophication?
- Which units of measurement do we use?
- What value or level of achievement will be classified as "well achieved", "not so well achieved" or "not achieved at all"?

We use "attributes" to define how the achievement of each objective can and will be measured. An attribute, also called the performance measure, is a variable that measures, either qualitatively or quantitatively, the extent to which the specific objective is achieved. Attributes are explicit as they define how an objective is interpreted and evaluated for the purposes of the decision. Attributes serve to eliminate the uncertainties associated with ambiguity in the objectives and should be easy to understand by everyone in a multi-stakeholder group.

In the following paragraphs, descriptions and justifications of the default objectives used in this manual, as well as their corresponding attributes, are provided.

HIGH TECHNICAL RELIABILITY

Did you ever experience how a technology fails to operate shortly after installation?
Or, how a technology, financed with external funding, was constructed but never operated?

Description of objective

A very technically reliable technology is one that is robust, operates reliably and requires as little downtime as possible per year.

There are many examples of technologies that, for one reason or another, fail to operate continuously. Some of the reasons for failure were already mentioned in Step 3 (e.g. climatic conditions and available resources)[3] , and can be represented under the following four different aspects:

- Availability of water
- Availability of energy
- Availability of equipment and spare parts
- Availability of skills

The failure of a technology is mostly related to the lack of one of these four aspects. Each aspect has a different impact on the operation of the technology and, therefore, will affect the downtime of the technology. The attribute we use to measure this objective is "downtime per year" (Table 24).

HIGH SOCIAL IMPACT

How does the technology impact and improve
the living conditions in the community?

Description of objective

A technology with a high social impact is one that contributes to the development of a community in terms of social comfort, equality and prosperity. It is assessed by three sub-objectives.

We know that technologies with a high social impact tend to be better accepted by communities, which then enhances their sustainability. Nevertheless, a proper social acceptance analysis consists of other aspects, some of which are tackled at the end of the report, in "Step 9: Final discussion".

If you stop to think about what other aspects could contribute to social impact, you will probably identify issues, such as gender equality, involvement of the poor, awareness and skill raising, training for the employees, etc. These are completely valid aspects that definitely contribute to the high social impact of an intervention. However, they do not depend on the technology, i.e. they are not technology-dependent. Remember, however, that our objective hierarchy should

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[3]Available funds were also mentioned, but this will be covered in the objective "high economic feasibility".

be composed of objectives that are technology-dependent, which means that each technology performs differently with regard to that objective.

The descriptions and attributes for each sub-objective are provided in Table 24.

HIGH ENVIRONMENTAL PROTECTION

Are you aware that some technologies pollute their surroundings through leachate or emissions more than others?

Description of objective

A technology that protects the environment is one that has few or no emissions into the surrounding water or air.

Organic waste treatment technologies are built and operated, among other reasons, to avoid biowaste from contaminating the environment. However, some biowaste treatment processes themselves might pose threats to the environment due to the generation of by-products. An appropriate and long lasting treatment technology should minimise potential impact on the environment. Environmental pollution mainly happens in two different ways: emissions into the atmosphere, and leachate into the surface- or ground-waters, which are the basis for the two sub-objectives named "low emission generation" and "low risk of eutrophication".

The descriptions and attributes for each sub-objective are provided in Table 24.

HIGH CONTRIBUTION TO WASTE MANAGEMENT

How much of the generated biowaste can be treated by the treatment unit? Does a residue after treatment still need to be disposed of?

Description of objective

A technology with a high contribution to waste management is one that can treat as much of the generated biowaste as possible and generates little residue.

The treatment technology needs to either eliminate the waste or turn it into a valuable or stable product. Some technologies cannot always treat 100% of the biowaste, or will generate non-marketable products, which need to be disposed of. The technology should be able to treat as much waste as possible and generate as little residue as possible. The objective consists of two sub-objectives: "high treatment capacity" and "low residue generation".

Physiochemical characteristics of the biowaste determine which treatment technology can be used, i.e. each technology performs best when the waste characteristics are within a specific range. Some technologies have narrower ranges than others and are, thus, more sensitive in terms of what feedstocks they can treat. Ideally, the treatment technology should be able to process as much of the generated waste as possible.

The descriptions and attributes for each sub-objective are provided in Table 24.

HIGH ECONOMIC FEASIBILITY

Have you experienced that certain technologies stopped because their operation was no longer profitable?

Description of objective

An economically feasible technology is one that generates enough revenue to cover at least all operation and maintenance costs, and ideally, make a profit.

The economic feasibility of waste treatment plants is a crucial aspect for their long term success. Experience shows us that unprofitable installations tend to be abandoned once the available budgets of the project are consumed or grant money by donors stop flowing. Therefore, ensuring a healthy economic performance is of upmost importance. Ideally, if a treatment plant makes a profit, the operators will use this business opportunity and make an effort to keep it running.

The description of the attribute is provided in Table 24

Table 24: Objectives and attributes definition

Objectives	Objective description	Attribute	Description attribute
High technical reliability *A very technically reliable technology is one that is robust, operates reliably and has as little downtime as possible per year.*		Maximum number of consecutive days of downtime per year (days/year).	- Method to assess this attribute can be found in section "High technical reliability" in Step 5.
High social impact *A technology with a high social impact is one that contributes to the development of a community in terms of social comfort, equality and prosperity.* This objective is assessed by three sub-objectives.			
Few working hazards	*A technology with few working hazards is one that allows safe working conditions, thereby having a high social impact.*	Percent (1 -100%) of maximum level of hazard the workers are exposed to per technology).	- Method to estimate this attribute can be found in section "Few working hazards" in Step 5. - Default values for each technology are given in Table 30.
Low nuisance level for the community	*A technology with a low nuisance level for the community is one that does not lead to significant nuisance by smell, inhalation of aerosols, noise and odour.*	Percent (1 -100%) of maximum level of nuisance the community suffers from per technology	- Method to estimate this attribute can be found in section "Low nuisance level for the community" in Step 5, p 78. - Default values for each technology are given in Table 33
High job creation	*A technology with high job creation is one that generates local employment, thereby having a high social impact.*	Number of workers employed	- Method to estimate this attribute can be found in section "High job creation" in Step 5.
High environmental protection *A technology that protects the environment is one that emits no or little emissions and leachate into the surroundings.* This objective is described by two sub-objectives.			
Low emission generation	The technology generates few or no emissions into the atmosphere (gases), thereby contributing to protecting the environment.	- CO_2 equivalents emitted to the atmosphere per day (kg CO_2 eq/day)	- Method to estimate this attribute can be found in section "Low emission generation" in Step 5
Low risk of eutrophication	The technology generates little or no leachate, thereby having a low risk of eutrophication and, thus, contributing to protecting the environment.	- Risk level to generate and discharge leachate to the environment (1 – 5)	- Method to estimate this attribute can be found in section "Low risk of eutrophication" in Step 5. - Default values for each technology are given in Table 34.
High contribution to waste management *A technology with a high contribution to waste management is one that can treat as much of the generated biowaste as possible and generates little residue.* This objective is described by two sub-objectives.			
High treatment capacity	*A technology with a high treatment capacity is one that can treat the majority of the generated biowaste.*	% of the collected waste that the technology can treat. (%)	- Method to estimate this attribute can be found in section "High treatment capacity" in Step 5.
Low residue generation	*A technology that generates little residual waste is one that eliminates or produces a marketable product out of the original amount*	% of the input waste that is converted into a non-marketable residue that requires disposal.	- Method to estimate this attribute can be found in section "Low residue generation" in Step 5. - Default values for each technology are given in Table 36.
High economic feasibility An economically feasible technology is one that generates enough revenue to at least cover all costs, and ideally make a profit		Ratio of revenue and expenditure (dimensionless).	- Method to estimate this attribute can be found in section "High economic feasibility" in Step 5.

VALIDATION OF OBJECTIVES

To ensure that the objective hierarchy is appropriate to your local context, we recommend using a stakeholder workshop to validate the objectives. After the workshop, some of the default objectives might not appear relevant and should, therefore, not be considered or new objectives are added. If new objectives need to be added, the next section entitled "Including new objectives and attributes" introduces some guidance and rules on how to proceed.

The workshop can be carried out with several stakeholders at the same time or individually.

MATERIALS NEEDED

These are the materials needed for the workshop:

- One paper sheet per participant with approximately 15 blank lines. Each line is numbered.
- Another paper sheet per participant containing the list of default objectives as shown in the objective hierarchy of Figure 29. This list will be referred to as the master list (an example of the master list can be found in Annex 3). Below this master list, there should be empty lines so that potential new objectives can be added.
- Pens.

STEP BY STEP DESCRIPTION OF THE WORKSHOP

1) Regardless of whether there are one or more participants, explain the context and the goal of the workshop.

2) Distribute a pen and a piece of paper to each participant with around 15 blank lines. The lines should be numbered so that the objectives can be referenced later.

3) Ask participants to list the objectives that matter to them. But, do not show them the default objectives yet. Try to reveal as little as possible about the default objectives as that might bias their opinions. If you need to give examples of objectives, try to think of a different decision problem, such as the example of the hotel used previously. It is usually best to ask people to write down their own ideas independently. The phrasing of these objectives will probably be very broad, but this is acceptable for now.

Example: *possible paragraph read out loud or distribute among participants (translated when necessary)*

Imagine that a new biowaste treatment technology will be implemented in your community/your neighbourhood/your district/your town (please adapt correspondingly). This facility could be run by a small business within the community or by the community itself or by the municipality. Such a facility will bring changes to the current waste management situation and will have an impact on different dimensions of sustainability (environment, economy or society). It should be appropriate for the community and it should be adequate to the local characteristics of resource availability (water, electricity, space, fuel, etc.). Please write down what goals this treatment technology should fulfil and what is needed to ensure the technology is useful and functional in the given context and what negative impacts should be avoided. Also, write what changes in the community you would like to see or not see as a result of this new facility. What benefits do you think the technology should offer or what problems should the technology solve?

Hint:

If you are having trouble getting a comprehensive list, you may need to prompt the participants with more questions. Ask them what would make them really happy: what are we trying to achieve or what concerns are we trying to address? Or, ask them to role play and imagine themselves as a different stakeholder. What would they be concerned about? If people have anchored on a particular solution (one specific technology), ask them to list what is so good about it; this list may contain great ideas for objectives. Conversely, if participants strongly oppose a proposed alternative, ask them why. What would they most want to avoid? The answers to these questions will yield information about objectives that have not been stated yet.

4) Group work (optional). Once every participant has written down their ideas you could allow them to have a brief discussion among themselves. This exchange might influence each participant's original opinion, but can also lead to a certain degree of consensus.

5) Distribute the master list with the default objectives.

6) Ask the participants to use the master list as follows (see master list in Annex 3):

Column A: Ask participants to put a check in the box next to any objective they think is relevant to the selection of a treatment technology.

Column B: Ask participants to compare their listed objectives on the first page with their checked objectives on the master list. Whenever an objective in the master list matches an objective listed by a stakeholder, the corresponding number (1-15) should be introduced in column B.

A participant who listed a very general objective on the first page might match that item to more than one objective on the master list.

Some of the objectives on the participants' lists might not match any objective in the master list. These should then be considered as potential new objectives that can be added to the hierarchy. Participants should judge if they consider these new objectives to be relevant or not. If the answer is yes, then they should be added below the existing objectives of the master list.

7) Thank the participants, collect all the notes and close the workshop.

ANALYSIS OF THE COLLECTED DATA

After the workshop, you can conclude with the objectives' validation:

- Study the master list of objectives and look at which of the objectives the participants checked as important.
- Assess the newly defined objectives and evaluate if they can really be considered as objectives.

If the workshop validates the existing objectives without addressing new ones, you can skip the following section and go directly to Step 5. Annex 4 presents two cases in which objectives need to be added or removed.

INCLUDING NEW OBJECTIVES AND ATTRIBUTES

The results from the workshop might show that you need to add new objectives. Or, you might have to add a new technology alternative as an option, which may lead you to think of unconsidered objectives. For instance, assume you run the case study where there is a shortage of fertilisers. "High nutrient recovery" could then turn to be a new sub-objective under the objective "high environmental protection".

If you need to add a new objective with its attribute, please follow the steps described in this section. If you have no new objectives to add, you can skip this chapter.

HOW DO YOU ADD A NEW OBJECTIVE?

For every new objective added, you should:

1) Check if the objective fulfils the six requirements of decision theory
2) Check if it is a fundamental or means objective
3) Check if it is an objective or a sub-objective
4) Phrase it in a consistent way
5) Define its attributes

1) Six requirements

Individual objectives must fulfil the following requirements:

1. Understandable: each objective should be described in a clear way so that it is understandable to everyone and be relevant to the decision problem.

Tip: objectives become more understandable thanks to a clear description of the sub-objectives and related attributes.

Example:

"High contribution to solid waste management" might be understood in different ways. The sub-objectives and specific attributes, however, help "define contribution to waste management". A low treatment capacity (i.e. a technology that can only treat a small part of the collected waste) or a "high residue generation" (i.e. a technology that generates a lot of residue) will mean this technology will leave more waste to be managed after the treatment than a technology that can treat more waste and generates less residue.

2. Measurable: the objectives should be measurable as accurately and unambiguously as possible.

Tip: as accurately as possible means that the measurement should pertain to what is really important to the decision maker. Unambiguously means that interpretation of the measurement should be clear and as undisputed as possible.

Example:

Assume you want to choose a dog with the objective of a low impact on the cleanliness of your house (by shedding of hair). The attribute "short haired", although measurable, will not be accurate as it is not directly related to hair loss. A more accurate objective would be "limited hair loss rate" with the attribute of degree of hair loss.

3. Independent: it is good practice to check that the objectives are independent of each other – or more formally, 'preferentially independent'. This means that they contribute independently to the overall performance of an alternative, and the one objective will not influence another objective.

Tip: the issues of independence are almost always solved when the objectives are carefully structured. Identifying and avoiding similar objectives is crucial.

Example:

A company is looking for a new production location. Among the objectives are "freeway access as near as possible" and "railway access as near as possible". A more detailed analysis may reveal that these objectives are not preferentially independent since an improved freeway access reduces the importance of a good railway access. These objectives are substitutive and can be substituted by a more accurate end-objective, such as "minimising transport time".

4. Complete: the complete set of objectives must consider all fundamental consequences that decision makers consider relevant. No essential objectives should be missing.

Tip: all consequences of the decision on environmental, social, economic, health, and cultural outcomes should be included. To assess if the objectives are complete, it helps to think through the alternatives and their possible features.

Example:

When you are deciding which dog to buy, you might consider the various dogs (alternatives) and then realize that one dog species (one alternative) is very hairy and that this is something to consider as it indirectly affects the cleanliness in your house. This could then lead you to include a new objective related to the dog's effect on cleanliness with an attribute of hairiness: something you might not have initially considered.

5. No redundancies: two or more objectives should not have an overlapping meaning.

Example:

When choosing a hotel, the meaning of objectives, such as "calm location", "quietness" and "no traffic", overlap. Such similar objectives are typically grouped together into one, and then sub-objectives are used to describe the components of the main objective. A good set of objectives ensures that all the important consequences can be described with the fewest possible sub-objectives.

6. Sensitive: this implies that the objectives are influenced by the alternatives under consideration. If all alternatives under consideration achieve the objective in the exact same way, then the objective does not help in distinguishing among the alternatives and can be omitted.

Example:

In the above example of the hotel, if all hotels have the same price, the objective "low price" is not sensitive and can be discarded. When choosing between different conference venues, for instance, one of our objectives might be "minimum commuting time from the train station". However, if all venues are 20 minutes from the train station, they will all score equally for this objective and, therefore, this objective is not sensitive.

2) Fundamental or means objective?

There is a very important distinction between "fundamental objectives" and "means objectives".

> **Fundamental objective:** this is an objective that is pursued for its own sake and that needs no further justification
>
> **Means objective:** this is an objective that is pursued because it helps achieve another more fundamental objective. Means objectives should not be in the objective hierarchy.

Hint:

In order to distinguish between fundamental objectives and means objectives, you always have to ask yourself: "why is this objective important?" or "why do I care about this?". If objective X is important only because it contributes to achieving another objective Y, you should omit objective X from the list and replace it by the fundamental objective Y instead.

You know you have a fundamental objective when the answer to the question of 'why is that important' is: 'it just is!'.

Example:

Some cities, for instance, pursue the following two objectives: high air quality and low noise pollution. These will be our fundamental objectives. A "means objective" to achieve this could be: reduce number of cars in the inner city.

Among other measures, road bottlenecks and a lack of public parking are well suited to reduce the number of cars. The means objective to reduce the number of cars in the inner city contributes to the fundamental objectives to improve air quality and reduce noise pollution.

However, air quality and noise pollution might also be affected by other factors besides cars. Therefore, "Low presence of cars in the inner city" should never be considered as a fundamental objective.

3) Objectives or sub-objectives?

Once you have actually come up with a fundamental objective, you may be disappointed to discover that it is rather vague. Now is a good time to ask the next set of key questions: what do you mean by that? Can we identify subcomponents of this objective? Fundamental objectives can be broken down into sub-objectives. For example, the objective "high social impact" is rather vague, and can be decomposed into several other important aspects that define it much better (i.e. "high job creation", "few working hazards", etc.). These aspects answer the question "what exactly determines "high social impact"?". On the other hand, the question of "why do I care about "high social impact"?" concerns the distinction between means and fundamental objectives. "High social impact" is just a prerequisite for the success of a technology! Consequently, it is a fundamental objective.

The purpose of the sub-objectives is to describe the objectives more precisely and to enhance their measurability. The box below gives a more detailed description.

Example: *Objectives and Sub-objectives*

Social acceptance is one of the objectives proposed. However, this objective is rather abstract and not suitable for the evaluation of alternatives. How well does an anaerobic digestion (biogas) facility achieve the objective of high social acceptance and how does that compare to a composting facility? What influences the degree of social acceptance?

To better quantify "social acceptance", the objective is broken down into several sub-objectives, such as "few working hazards", "low nuisance level for the community" and "high job creation". Each of these sub-objectives describes one certain aspect of the objective "social acceptance".

The same applies to the objective of environmental protection. How well does a composting plant achieve the objective environmental protection and how does this compare to another biowaste treatment technology? To better describe environmental protection, the objective was broken down into two sub-objectives: "low emission generation" and "low risk of eutrophication". These two sub-objectives are more straightforward regarding their contribution to environmental protection and can be more easily evaluated.

If a new objective needs to be added to the objective hierarchy, you should check whether it is an objective on its own or whether it is a sub-objective in one of the existing branches of the hierarchy.

4) Phrasing new objectives

With a new objective that fulfils the above requirements, the next step is to phrase it in a concise way and to assign a direction to it. Phrase the objectives with no more than three to four words. An adjective or an adverb should be added to indicate the desired direction of change (e.g. ***high*** economic feasibility, ***low*** risk of eutrophication, etc.).

HOW DO YOU DEFINE A NEW ATTRIBUTE?

A new objective should be assigned an attribute that can be measured in order to determine the extent that the objective is achieved by the technology alternative. Selecting attributes is subjective, and both technical and value judgments are relevant. Phrasing the attributes is, therefore, very important. Check the following example which shows how worker safety in American coal mines could be characterised using any of these apparently reasonable metrics (Gregory et al., 2012):

1. Number of deaths from coal mining in the United States per year.
2. Number of deaths from accidents per ton of coal mined in the United States per year.
3. Number of deaths from United States coal mining accidents per employee per year.

The interesting part is that each of these metrics suggests a different story with respect to worker safety. Looking backwards, over the 1950–1970 period, the first metric remained relatively constant. The second – accidents per ton of coal – decreased, the result of increased mechanisation. The third metric – deaths per employee – increased for the same reason. Looking forward, the choice among these could matter in terms of ranking investments in coal mining. How does this relate to worker safety? Did it improve or not? Well, the answer is not self-evident – and each of these metrics provides only part of the complete picture.

Although there are arguably no 'right' or 'wrong' attributes, there are certainly better and worse ones. Important properties of good attributes are listed below (Keeney et al., 2005):

1. Direct, meaning that attributes should relate as directly as possible to the achievement of a given objective or sub-objective.

Example:

The sub-objective of "low smell impact" for a given technology alternative can be measured by the "number of community complaints because of smell", assuming the technology alterative already exists in the region or country. However, the number of complaints may be related to the possibilities the residents have to voice a complaint and not necessarily to the actual smell emission of the technology. One could then think of measures that effectively reduce the number of complaints, but at the same time do not reduce the smell impact of the technology (when compensating remunerations are given, for instance). Therefore, directly measuring the actually relevant attribute "concentration of SO_x and NH_3 in the air 10 m from the technology" would be the superior choice if this can be measured reliably.

2. Operational, meaning that attributes are only useful if they can be put into practice within relevant budgets and timelines and the required information to assess them is available, whether from data, models, expert judgments, or other sources.

Example:

It might be theoretically possible to measure the threat to biodiversity by a technology, using gas or leachate emissions of the technology, the potential damage of those emissions to ecosystems and their impact on different species. However, the effort required to determine these values would probably be unreasonably high, with quite uncertain results.

3. Understandable, meaning that attributes, and what they describe, can be easily understood and communicated clearly. This is critical in a multi-stakeholder context to ensure that no misunderstandings occur.

Example:

Would you be able to say what level of biological oxygen demand of the leachate reaching underground water bodies you would be willing to accept? Probably not, and if yes, it will certainly not be understandable to the general public. In cases when such specific parameters are used, it is good to provide easy comparisons that the participants involved in the assessment could refer to. For instance, a bucket full of human faeces has X grams of biological oxygen demand. Participants can easily visualise such a bucket and the impact it would have on a water body.

4. Unambiguous, meaning that for each attribute, a clear, accurate, and well recognised relationship should exist between the value measured by the attribute and the objective performance it describes. It is important that this performance be interpreted in the same way by different people.

Example:

Measuring "high technical reliability" using three levels, namely low, medium, and high, is relatively vague and could be interpreted differently by different people. By contrast, the number of days of downtime per year is a more unambiguous definition that does not leave much room for differing interpretation.

5. Comprehensive, meaning that an attribute meets these two properties: its covers the full range of possible consequences, and any implicit value judgments are appropriate for the decision problem.

Example:

Assume we want to set a national ambient air quality standard for carbon monoxide. Breathing more carbon monoxide leads to detrimental health effects. These include fatal and nonfatal heart attacks. Now, consider the attribute "number of fatalities" for this objective. This attribute does not cover the full range of possible consequences, as not all detrimental health effects are fatal heart attacks; therefore, it would not be *comprehensive*. Instead, one could consider a composite attribute, including both nonfatal and fatal consequences.

The second property of value judgments is clearly seen with attributes that involve counting, such as the number of fatalities, and there is the assumption that each of the items counted is equivalent. This assumes that the death of a 10-year-old is equivalent to the death of a 90-year-old. Many people do not agree with this, as they consider the death of the 10-year-old to be more significant. One way to account for this is to use the attribute "years of life lost". If the expected lifetime of a 10-year-old is 80, then 70 years of life is lost if a 10-year-old dies. If the expected lifetime of a 90-year old is 95, then five years of life is lost.

STEP 5:
How do the technologies perform for each objective? Performance estimation

Here is a brief summary of what you should already have prepared before diving into this fifth step:

- a well delimited study area,
- a quantity and characterisation estimate for the targeted biowaste
- a list of stakeholders who you consider relevant,
- a selection of biowaste treatment technologies
- a validated objective hierarchy with corresponding attributes

Now, it is time to estimate the performance of each technology for every objective in the hierarchy! This is the content covered in this chapter.

How do we estimate the performance of each technology for every objective? For each technology alternative, we assign values to the attributes of each objective. These values represent the performance of the technology towards this objective. Let us use an example.

Example: *Technical reliability of vermicomposting*

The objective "high technical reliability" is measured by the attribute "days of downtime per year". For the technology alternative "vermicomposting" in an arid climate location, we have established that the vermicomposting plant will not be operational for 60 days during the year due to excessive temperature and conditions that are too dry in the vermicomposting beds. The attribute value of 60 days downtime per year, therefore, elucidates the performance of a vermicomposting plant related to the objective of "high technical reliability".

Now, value should be assigned to each attribute of each objective for each technology. These performance estimations will then allow us to compare the technologies to each other (Steps 6 and 7). But, how do we estimate the values of each attribute for each technology?

In this manual, we distinguish between two types of objectives with their attributes, depending on how difficult they are to estimate:

1) Easy to estimate: The non-case-specific objectives and attributes
2) Not so easy to estimate: Case-specific objectives and attributes

Table 25 presents the classification of the objectives based on these two types. Notice that the main objectives, which consist of sub-objectives, are not shown in the table (i.e. "high social impact", "high environmental protection" or "high contribution to waste management". Only their sub-objectives are presented. Do not worry about this. This is because the performance of the main objectives is an aggregation of the corresponding sub-objectives. This will become clearer in Step 7 and Step 8.

Table 25: Classification of objectives based on whether they are case-specific or not

Non-case specific objectives	Case specific objectives
• Few working hazards • Low nuisance level for community • Low risk of eutrophication • Low residue generation	• High treatment capacity • High job creation • High technical reliability • Low emission generation • High economic feasibility

This section includes a descriptive methodology to evaluate each one of the objectives and attributes. For the "case-specific objectives" the example of the City of San Fernando, in the Philippines will be used. Your ultimate goal is to complete a table similar to Table 26. In this table, we summarise the performance estimations of all technologies for every objective, considering the case of CSF.

Table 26: Estimated attribute values for different technology alternatives for the case of CSF

Main Objectives	Sub-objectives	Attributes	Windrow Composting	In-vessel composting	Vermicomposting	AD	BSF	Slow Pyrolysis
High technical reliability	-	Days per year of downtime (day/year)	23	53	27	0	60	0
High Social impact	Few working hazards	Percent of maximum level of hazard the workers are exposed to per technology (%)	25.7	15.8	17.8	13.8	15.1	47.4
	Low nuisance level for community	Percent of maximum level of nuisance the community suffers from per technology (%)	75	67.9	64.3	35.7	71.4	75
	High job creation	N° of workers per ton of waste treated per working day (worker/ton per day)	3	2.5	1	1	3	4
High environmental protection	Low emission generation	Emission of CO_2 eq.. per day (kg CO_2 eq./day)	163	81	3.5	39	2.1	365
	Low risk of eutrophication	Leachate-risk level (1-5)	2	1	3	1	2	1
High contribution to waste management	High treatment capacity	Percentage of the collected biowaste that can be treated by the technology (%)	60.5	60.5	37.5	37.5	37.5	62.5
	Low residue generation	Percentage of residue over original wet waste (%)	0	0	0	100	32.5	0
High economic feasibility	-	Income-expenditure ratio (-)	0	0	0.24	1.3	1.7	1.8

NON-CASE SPECIFIC OBJECTIVES/ATTRIBUTES

For some objectives and attributes, this manual already suggests values which we assume to be valid for a "general" situation. These are attribute values that depend on the functional properties of the technology itself and are determined based on literature review and expert judgement. The performance of each technology against these attributes depends less on the location and context of where the technology is implemented. That is why we call these "non-case-specific objectives and attributes". However, one should take them as what they really are: estimates. They serve the purpose of representing the relative performance differences between the technologies. When values are shown as ranges, the average can be used or else expert judgement can be used to define the best value. Nevertheless, the decision of which value to use should be well justified and made transparent. In this section, the following non-case specific objectives will be presented:

- Few working hazards
- Low nuisance level for community
- Low risk of eutrophication
- Low residue generation

FEW WORKING HAZARDS

This objective is measured by the attribute "percentage of the maximum level of hazard that the workers are exposed to". The unit of measurement is, therefore, a percent (%).

Attribute	Unit
Percentage of maximum level of hazard the workers are exposed to per technology	Percent (%)

Biowaste treatment technologies may pose potential risks for human health and safety. Although the potential human risks and monetary costs are considerable, there is little useful information available to biowaste managers for reducing such risks. No health assessments were found in the literature for most treatment technologies considered in this manual. Therefore, literature on health and safety risks in solid waste management was consulted (Englehardt et al., 2000; Cointreau, 2006). Many health hazards, which are also applicable to biowaste management, were identified. Table 29 provides the final list of health hazards considered in this manual. A severity value is assigned to each hazard. This indicates the degree of seriousness for each hazard (Table 27).

Table 27: Severity scale for health hazards

Value	Description
1	Negligible
2	Minor health and safety effect
3	Moderate health and safety effect
4	Major, critical health and safety effect that can be controlled
5	Catastrophic, major health and safety effect with very restricted control or cannot be controlled

The probability of these hazards occurring is different for each technology. Five different probabilities are distinguished, shown in Table 28.

Table 28: Probability values given to health hazards

Value	Description
1	Unlikely, may not occur
2	Seldom, unlikely but possible to occur
3	Occasionally, but likely to occur sometimes
4	Likely to occur sometimes
5	Occur frequently

Table 30 shows the estimated probabilities of each hazard for each technology, as well as the overall scores per technology. In order to assign an overall score to each technology, the following procedure should be followed:

1. The probability of each hazard occurring is determined for each technology
2. The probability values are multiplied by the severity values of the corresponding hazard
3. All the scores obtained by multiplying severity values and probability values are summed up to obtain the overall score

Table 29: List of potential health hazards in biowaste management

Hazard or exposure	Description	Severity	Reference
Contact with chemicals improperly disposed of	Often, biowaste is not properly segregated and other substances and materials appear mixed with it. The probability of being in contact with chemicals is higher in manually handled installations than in commercial scale installations where waste is manipulated with machines. Some of this substances might lead to dermatological problems, such as eye and skin irritation, allergies, etc.	3	(Englehardt et al., 2000) (Jerie, 2016) (Domingo et al., 2009)
Contact with sharp and broken objects	Due to the poor segregation of biowaste, sharp or broken items (glass, needles, metals, etc.) may appear. The probability of being in contact with sharp objects is higher in manually handled installations than in commercial scale installations where waste is manipulated with machines. These may cause lacerations, punctures or abrasions.	3	(Englehardt et al., 2000) (Jerie, 2016)
Contact with hot surfaces	Thermochemical treatment technologies occur at elevated temperatures. These may expose workers to hot surfaces or even fire, leading to burns, as well as eye and skin irritation.	3	-
Contact to pests	Biowaste poses a threat to public and environmental health as it attracts insects, rodents and other disease vectors. Workers at a biowaste treatment plant might be exposed to such pests.	3	(Lohri et al., 2017) (Jerie, 2016)
Inhalation of CO_2	No documented health effects, potential asphyxiation and cardiovascular and/or neurologic damage	1	(Englehardt et al., 2000)
Inhalation of CO	The symptoms of carbon monoxide poisoning are often described as "flu-like" and commonly include headache, dizziness, weakness, vomiting, chest pain, and confusion. Extended periods of exposure can result in loss of consciousness, arrhythmia, seizures, or death.	3	(CDC, 2015)
Inhalation of CH_4	Methane gas itself is not toxic, but if it is allowed to fill an enclosed room it can displace the oxygen to lower than 18% of the air and act as an asphyxiant. When this happens, common symptoms are feelings of dizziness, headaches, increased heart rate and a loss of coordination. This might only happen when an anaerobic digestion is constructed indoors and leaks the produced methane. The amount leaked often depends on the reactor type.	2	(ToxTown, 2017)
Inhalation of PAH	Many Polycyclic Aromatic Hydrocarbons (PAH) have toxic, mutagenic and/or carcinogenic properties. Epidemiologic reports of PAH-exposed workers have noted increased incidences of skin, lung, bladder, and gastrointestinal cancers.	4	(Abdel-Shafy et al., 2016) (ATSDR, 2013)

Hazard or exposure	Description	Severity	Reference
Inhalation of bioaerosols (organic dust)	Bioaerosols are particles of microbial, plant or animal origin and may be called organic dust. They can include live or dead bacteria, fungi, viruses, allergens, bacterial endotoxins (components of cell membranes of Gram-negative bacteria), antigens (molecules that can induce an immune response), toxins (toxins produced by microorganisms), mycotoxins (toxins produced by fungi), glucans (components of cell walls of many moulds), pollen, plant fibres, etc. Biowaste is a source of microorganisms. Collecting and handling biowaste creates bioaerosols and these are inhaled when working. Bioaerosols are known to cause symptoms such as dry cough, exercise induced dyspnea, asthma, chronic bronchitis, organic dust toxic syndrome (ODTS), chest tightness, fever, flu symptoms, allergic or non-allergic pulmonary diseases, inflammation and irritation of airways, headache, joint and muscle pain, fatigue, diarrhoea, nausea, and acute gastrointestinal symptoms.	4	(Englehardt et al., 2000) (Rashidi et al., 2017) (Domingo et al., 2009) (Pearson et al., 2015) (Cointreau, 2006) (Bünger et al., 2007)
Manual handling activities	Manual handling activities, such as lifting, lowering, pushing, pulling and carrying, are the main cause of musculoskeletal disorders (MED). If such tasks are not carried out appropriately, there is a risk of injury. MED can be both acute (sudden injury) or chronic (cumulative injury), and typical examples are: disorders of the neck, shoulder and back, tendon diseases, extreme pain, and lumbar disc prolapse.	4	(Englehardt et al., 2000) (HSE, undated-a) (Jerie, 2016)
Noise	Noise hazards are globally ranked among the top five occupational stressors with grave repercussions to the worker. Continuous occupational noise exposures of 85–90 dB can lead to adverse health conditions on workers, such as Noise Induced Hearing Loss (NIHL) and increased blood pressure.	3	(HSE, undated-b) (Jerie, 2016) (Ncube et al., 2017) (Cointreau, 2006)
Long periods of work with machinery	Injuries and musculoskeletal disorders	2	(Englehardt et al., 2000) (Jerie, 2016)
UV/IR radiation	Working under the sun can cause dermatological problems or sunstroke.	2	(Jerie, 2016)

Table 30: Probability of occurrence of each hazard and final rating for each technology

Technology	Use		Contact with chemicals	Contact with sharp objects	Contact with hot surfaces	Contact to pests	Inhalation of CO_2	Inhalation of CO	Inhalation of CH_4	Inhalation of PAH	Inhalation of Microorganisms	Manual handling	Noise	Long periods of machinery	UV/IR radiation	Overall rating	Overall score
		Severity	3	3	3	3	2	3	2	4	4	4	3	2	2		
Windrow composting	Self-use	Prob. value	3	3	1	3	2	1	1	1	4	4	1	1	4		
		Rating	9	9	3	9	4	3	2	4	16	16	3	2	8	88	32.9
	Commercial	Prob. value	1	1	1	2	2	1	1	1	4	2	3	4	4		
		Rating	3	3	3	6	4	3	2	4	16	8	9	8	8	77	25.7
In-vessel composting	Self-use	Prob. value	2	2	1	2	1	1	1	1	2	3	1	1	2		
		Rating	6	6	3	6	2	3	2	4	8	12	3	2	4	61	15.1
	Commercial	Prob. value	1	1	1	2	1	1	1	1	2	2	4	2	2		
		Rating	3	3	3	6	2	3	2	4	8	8	12	4	4	62	15.8
Vermi composting	Self-use	Prob. value	3	3	1	3	2	1	1	1	3	4	1	1	3		
		Rating	9	9	3	9	4	3	2	4	12	16	3	2	6	82	28.9
	Commercial	Prob. value	1	1	1	2	2	1	1	1	2	2	3	3	3		
		Rating	3	3	3	6	4	3	2	4	8	8	9	6	6	65	17.8
Anaerobic digestion	Self-use	Prob. value	3	3	1	2	2	1	2	1	1	3	1	1	2		
		Rating	9	9	3	6	4	3	4	4	4	12	3	2	4	67	19.1
	Commercial	Prob. value	1	1	1	2	2	1	2	1	1	2	3	2	2		
		Rating	3	3	3	6	4	3	4	4	4	8	9	4	4	59	13.8
Black Soldier Fly	Self-use	Prob. value	3	3	1	3	2	1	1	1	3	4	1	1	2		
		Rating	9	9	3	9	4	3	2	4	12	16	3	2	4	80	27.6
	Commercial	Prob. value	1	1	1	2	2	1	1	1	2	2	3	2	2		
		Rating	3	3	3	6	4	3	2	4	8	8	9	4	4	61	15.1
Slow Pyrolysis	Self-use	Prob. value	2	3	4	2	3	3	1	3	5	5	2	1	3		
		Rating	6	9	12	6	6	9	2	12	20	20	6	2	6	116	51.3
	Commercial	Prob. value	1	3	4	2	3	3	1	3	4	4	3	2	3		
		Rating	3	9	12	6	6	9	2	12	16	16	9	4	6	110	47.4

In Table 30, we see that the overall scores per technology range from 13.8 (anaerobic digestion, commercial scale) to 51.3 (slow pyrolysis, self-use). These are default values that can be used by any user of this manual. However, the severity or the probability values can be adapted based on the local context. For instance, if the probability of the biowaste containing chemicals due to poor segregation is 100%, the probability for the hazard contact with chemicals can be increased and the values recalculated.

Theoretically, considering the severity and probability values used in Table 30, the minimum rating that a technology could obtain is 38 (by multiplying the severity values considered by 1 and then adding all of them). And the maximum possible rating that a technology could obtain is 190 (multiplying all severity values by 5 and then adding them). Therefore, our scale ranges from 38 – 190. We can convert these values into a scale that goes from 0 – 100 for it to be more intuitive by using Equation 10.

Equation 10

$$S = \frac{R - Min_R}{(Max_R - Min_R)} \cdot 100$$

Where:

- S: Overall score
- R: Rating obtained
- Min_R: Minimum rating possible. If the same severity values are used, this value will always be 38.
- Max_R: Maximum rating possible. If the same severity values are used, this value will always be 190.

According to Table 30, biowaste treatment using slow pyrolysis (self-use) is the technology with the highest hazard exposure percentage, whereas a commercial scale anaerobic digestion will score the lowest and, therefore, it is the safest technology for workers.

Step 5

LOW NUISANCE LEVEL FOR THE COMMUNITY

This objective is measured by the attribute "Percent of maximum level of nuisance the community suffers from". The unit of measurement is, therefore, a percent (%).

Attribute	Unit
Percentage of maximum level of nuisance the community suffers from per technology	Percent (%)

People living and working in the vicinity of biowaste processing suffer from nuisance. These nuisances include the emissions from the biowastes and the operational activities of each plant. Four main nuisance types were identified: pest proliferation, inhalation of bioaerosols (organic dust), noise and smell.

Pest proliferation

Vector-related diseases remain an important public health threat throughout low- and middle-income settings. The organic materials in waste provide breeding sites for insects and rodents (Cointreau, 2006). Biological hazards associated with pests proliferating on biowaste that can be transmitted to the community nearby include waterborne diseases resulting from flies and mosquitoes breeding on the waste. Rabies may be caused by the bites of rabid dogs and rodents may also spread disease. Zoonosis may result from the bites of wild or stray animals feeding on waste, and enteric infections transmitted by insects (Jerie, 2016).

Inhalation of bioaerosols (organic dust)

Bioaerosols are particles of microbial, plant or animal origin and may be called organic dust. They can include live or dead bacteria, fungi, viruses, allergens, toxins, glucans, pollen and plant fibres. Microorganisms are frequently absorbed onto dust particles and will be transported along with the dust. Exposure to bioaerosols depends on several factors, such as how the biowaste is managed (agitation of material, turning, screening, shredding, covered or uncovered, etc.), wind intensity and direction, and relative humidity and precipitation. A number of studies show that concentrations of bioaerosols downwind of outdoor composting facilities are elevated above background levels at times to distances on the order of 200 to 800 meters (Caroline E. W. Herr et al., 2003; C. E. W. Herr et al., 2004; Fischer et al., 2008; Domingo et al., 2009). We assume smaller severity values for all other technologies, especially if they are containerised (in-vessel composting and AD).

Odour annoyance

Wherever bulk quantities of waste are handled, kept, treated or disposed of, there is potential for the generation of offensive odours. Biowaste frequently presents significant odour challenges and problems during their handling and can decompose quickly under certain conditions producing odours that most people consider annoying and unpleasant.

Odours are caused by chemical emissions and are not bioaerosols. Compounds causing odours are not generally present outside of the treatment plant at concentrations high enough to cause illness; however, excessive odours can result in symptoms, such as nausea. Odour-causing compounds from biowaste degradation include reduced sulphur compounds (due to anaerobic conditions), ammonia, reduced nitrogen compounds, and volatile organic compounds (VOC) (Domingo et al., 2009). Of these, ammonia appears to be the most prevalent onsite odour causing compound within treatment facilities, while reduced nitrogen compounds and volatile organic acids appear to be the most notable contributors to offsite odours (MDEP, 2009). Odour annoyance is one of the common complaints from residents living nearby waste treatment facilities.

Half of the considered technologies elicit potentially great odour annoyances (windrow composting, BSF processing, and slow pyrolysis). Severity values in the range of 4-5 were assigned. In-vessel composting and vermicomposting were given lower values (3-4), whereas anaerobic digestion, being an enclosed technology, obtained the lowest odour severity values (2).

Noise pollution

Working or living in areas with high levels of noise pollution can cause long-term effects to human hearing. Many of the waste-related activities can represent sources of noise, particularly in the commercial scale and mechanised options. In the case of low- and middle-income countries, it is rare to be required to address noise safety standards (Cointreau, 2006). Consequently, operations can reach higher noise levels. Noise control is not routinely specified in equipment tenders and when noise levels are high, community annoyance is a common risk. All of the commercial scale plants considered were given a severity value of 3-4, whereas the small scale-manual plants presented severity values of 1 except for slow pyrolysis, which was assigned a 2, and in-vessel composting, which was assigned a 3 due to their mechanical components that, even if operated manually, are a source of noise.

The communities' quality of life living near a treatment plant can be jeopardised by these nuisances. The degree of nuisance is, however, different for each nuisance type. Table 31 shows the different "degree values" considered when assessing the nuisance types.

Table 31: Severity of nuisance considered

Value	Description
1	Negligible
2	Minor nuisance impact
3	Moderate nuisance impact
4	Major, critical nuisance impact that can be controlled
5	Catastrophic, major nuisance impact with very restricted control or cannot be controlled

The probability of occurrence of these nuisances is different for each technology. Five different probabilities are distinguished, and shown in Table 32.

Table 32: Probability values given to nuisance types

Value	Description
1	Unlikely, may not occur
2	Seldom, unlikely but possible to occur
3	Occasionally, but likely to occur sometimes
4	Likely to occur sometimes
5	Occur frequently

Table 33 shows the estimated probabilities of each nuisance type for each technology, as well as the overall scores per technology. In order to assign an overall score to each technology, the following procedure was followed:

1. The probability of occurrence of each nuisance type is determined for each technology.
2. The probability values are multiplied by the severity values of the corresponding nuisance.
3. All the scores obtained by multiplying severity values and probability values are summed up to obtain the overall score.

Table 33: Probability of occurrence of each nuisance and final rating for each technology

			Pest s	Bio aerosols	Noise	Odour	Overall rating	Overall score
		Severity	4	2	4	4	-	-
Windrow composting	Self-use	Prob. value	3	4	1	4		
		Rating	12	8	4	16	40	53.6
	Commercial	Prob. value	3	4	3	5		
		Rating	12	8	12	20	52	75.0
In-vessel composting	Self-use	Prob. value	2	2	3	3		
		Rating	8	4	12	12	36	46.4
	Commercial	Prob. value	3	2	4	4		
		Rating	12	4	16	16	48	67.9
Vermi composting	Self-use	Prob. value	3	3	1	3		
		Rating	12	6	4	12	34	42.9
	Commercial	Prob. value	3	3	3	4		
		Rating	12	6	12	16	46	64.3
Anaerobic digestion	Self-use	Prob. value	3	1	1	2		
		Rating	12	2	4	8	26	28.6
	Commercial	Prob. value	2	1	3	2		
		Rating	8	2	12	8	30	35.7
Black Soldier Fly	Self-use	Prob. value	4	3	1	4		
		Rating	16	6	4	16	42	57.1
	Commercial	Prob. value	3	3	3	5		
		Rating	12	6	12	20	50	71.4
Slow Pyrolysis	Self-use	Prob. value	2	5	2	4		
		Rating	8	10	8	16	42	57.1
	Commercial	Prob. value	2	4	4	5		
		Rating	8	8	16	20	52	75.0

In Table 33, we see that the overall scores per technology range from 28.6 (anaerobic digestion, self-use scale) to 75 (windrow composting and slow pyrolysis, both commercial scale). These are default values that can be used by any user of this manual. However, the severity or the probability values can be adapted based on the local context. For instance, if the presence of pests (flies, rodents, etc.) is perceived as a major nuisance by a community, its severity could be increased to 5 and the values recalculated.

Considering the severity and probability values used in Table 33, the minimum rating that a technology could obtain is 14 (by multiplying the severity values considered by 1 and then summing all of them). The maximum possible rating that a technology could obtain is 70 (multiplying all severity values by 5 and then summing them). Therefore, our scale ranges from 14 – 70. We can convert these values into a scale that goes from 0 – 100 for it to be more intuitive by using Equation 11.

Equation 11

$$S = \frac{R - Min_R}{(Max_R - Min_R)} \cdot 100$$

Where:

- S: Overall score
- R: Rating obtained
- Min_R: Minimum rating possible. If the same severity values are used, this value will always be 14.
- Max_R: Maximum rating possible. If the same severity values are used, this value will always be 70.

Step 5

LOW RISK OF EUTROPHICATION

This objective is measured by the attribute "risk level of generating and discharging leachate into the environment". The unit of measurement is, therefore, a value that ranges from 1 to 5.

Attribute	Unit
Risk level of generating and discharging leachate into the environment	Risk level 1 – 5

Determining the risk of eutrophication of the technologies is complex. In order to assess the risk of eutrophication of the technologies, the likelihood of generating leachate (a liquid by product) that may be discharged into the environment was estimated. Leachate can infiltrate into the surrounding soil and potentially contaminate the groundwater resources. Leachate risk level 1 implies that there is no production of liquid effluent from the treatment technology and leachate risk level 5 indicates that the treatment technology always generates a liquid effluent.

As leachate may also be generated when rain flows through waste as it is being processed, those treatment technologies that expose the waste to rainfall are considered to have a higher leachate risk level. The values provided in Table 34 should be adjusted based on the technology you foresee being built.

Table 34: Default values for risk of eutrophication

Technology	Variation	Description	Default
Windrow Composting	Not covered or No leachate collection	Leachate production is increased due to rain and it is discharged to the environment.	4
	Covered No leachate collection	No exposure to rain. Only usual leachate production. Discharged to the environment.	2
	Leachate recirculation	Regardless of whether they are covered or not, leachate is not discharged to the environment.	1
In-vessel composting	-	This technology generates no leachate.	1
Vermi composting	Not covered or No leachate collection	Leachate production is increased due to rain and it is discharged to the environment.	4
	Covered No leachate collection	No exposure to rain. Only usual leachate production. Discharged to the environment.	3
	Leachate recirculation/collection	Regardless of whether they are covered or not, leachate is not discharged to the environment.	1
Anaerobic digestion	Digestate discharged to environment	Big volumes of water enriched with nutrients are discharged to the environment	5
	Digestate safely used/ discharged	Digestate is not discharged to the environment. It is either used as fertiliser or treated beforehand.	1
BSF	Not covered No leachate collection	Leachate production is increased due to rain and it is discharged to the environment.	4
	Covered No leachate collection	No exposure to rain. Only usual leachate production. Discharged to the environment.	2
	Leachate collection	Leachate is not discharged to the environment. It is either used as fertiliser or treated beforehand.	1
Slow Pyrolysis	-	This technology generates no leachate.	1

CSF – CASE STUDY

The composting and BSF technologies considered in the assessment for the City of San Fernando did not include leachate collection. The digestate generated in the anaerobic digestion process will be discharged to the sewer system, and will ultimately be treated before discharge. Therefore, the risks of eutrophication per technology are as shown in Table 35.

Table 35: Risk values of eutrophication per technology in CSF

	Windrow Composting	In-vessel composting	Vermi-composting	AD	BSF	Slow Pyrolysis
Risk of eutrophication	2	1	3	1	2	1

LOW RESIDUE GENERATION

This objective is measured by the attribute "mass of the residue that remains after the treatment process over the total input mass of biowaste". The unit of measurement is, therefore, a percent (%).

Attribute	Unit
The mass of the residue that remains after the treatment process over the total input mass of biowaste (wet basis)	Percent (%)

Equation 12

$$\text{Residue Generation (\%)} = \frac{\textit{Mass residue (wet basis)}}{\textit{Mass input biowaste (wet basis)}} \cdot 100$$

Quantifying this attribute can be achieved by talking with experts or studying literature and case studies. An example of a question that could be asked is:

- When biowaste is treated with your technology, is there any residue generated?

Residues refer to the output of treated waste which does not have a market value and, thus, is treated like ordinary waste. If, assuming you are treating 100 kg of wet biowaste, how many kg of residue will you get after the treatment?

Table 36 details the percentages given to each technology. The explanations apply for both the self-use and commercial scales.

Table 36: Default values for residue generation per technology

<table>
<tr><th>Technology</th><th>Description</th><th>Default %</th></tr>
<tr><td>Windrow Composting</td><td rowspan="3">In the case of the three composting technologies considered in this manual, there are two types of residues: material which will not degrade aerobically due to their inert nature (plastics, glass, metals, sand, stones, etc.) and oversized organic material which will not be degraded, unless it is chopped.

These two aspects depend entirely on a proper source separation of the original biowaste. In this manual, we assume that the biowaste is well segregated, which implies that there will be almost no residues and, consequently, we assume 0% as a default value for this attribute.

The possibility to calculate the percentage of inert material and/or oversized organic material over the total mass is left to the users of the manual.</td><td>0%</td></tr>
<tr><td>In-vessel composting</td><td>0%</td></tr>
<tr><td>Vermi composting</td><td>0%</td></tr>
<tr><td>Anaerobic digestion</td><td>In the case of anaerobic digestion, the percentage of residue depends entirely on the marketability of the digestate generated (check section Market assessment). If there is a demand for the digestate, there will not be any residue generation. Alternatively, if the digestate is not commercialised, the residue will be 100% of the mass of the original input biowaste (in practice, if the biowaste is diluted in water, the percentage could be over 100%, but for the sake of simplicity, in a worst case scenario we will consider 100%).</td><td>0 or 100%</td></tr>
<tr><td>BSF</td><td>The BSF processing generates two outcome products: larvae and residue. The residue is the biowaste that is left after the larvae have fed on it. Assuming a mass reduction of the input biomass of 50 – 80% (Table 16), we expect 20 – 50% of residue (based on mass of input biowaste). Once more, the marketability of the residues determines how much residue is left. If there is a demand for the residue, there will not be any waste left, whereas if this is no demand, it will be left for further management or disposal.</td><td>0 or 20-50%</td></tr>
<tr><td>Slow Pyrolysis</td><td>In the case of slow pyrolysis, it is assumed that only those biowaste fractions suitable for pyrolysis will be treated with this technology. Assuming that the treatment requirements are met, all the biowaste will be converted into gases and char and, therefore, there will be no residue.</td><td>0%</td></tr>
</table>

CSF – CASE STUDY

In the case of the City of San Fernando, there was no demand for the digestate from anaerobic digestion, nor for the residues from BSF. Table 37 summarises the residue values considered.

Table 37: Residue generation values per technology in CSF

	Windrow Composting	In-vessel composting	Vermi-composting	AD	BSF	Slow Pyrolysis
Residue generation	0%	0%	0%	100%	32.5%	0%

CASE-SPECIFIC OBJECTIVES/ATTRIBUTES

The performance of the technologies for certain objectives and attributes depends strongly on the location and context of where the technology is implemented. This means that local, context specific information needs to be collected before a value can be assigned. In the coming pages, the methodology for the following case-specific objectives will be introduced:

- High treatment capacity
- High job creation
- High technical reliability
- Low emission generation
- High economic feasibility

HIGH TREATMENT CAPACITY

This objective is measured by the attribute "Percentage of collected biowaste that can be handled by each treatment technology". The unit of measurement is, therefore, a percent (%).

Attribute	Unit
Percentage of collected biowaste that can be handled by each treatment technology.	Percentage of total collected biowaste (%)

As you might remember, not all technologies are suitable for all sorts of biowastes. From all the biowaste generated and collected in your case study, we first need to check how much of that amount can be treated by each technology. That is what this attribute intends to do. In order to get this amount, we will use three parameters that affect the treatment suitability of biowaste for a given technology: C:N ratio, moisture and wood material content.

Table 38 shows the adequate ranges of each parameter per technology, as already presented in Table 21, in Section "Nature of available biowaste".

Table 38: Acceptable ranges of moisture, C:N and woody material (Copy of Table 21)

Parameter	Windrow Composting	In-vessel composting	Vermi-composting	AD	BSF	Slow Pyrolysis
Range of acceptable Moisture	Coarse biowaste: 70 - 75% Fine biowaste: 55 - 65%	Coarse biowaste: 70 - 75% Fine biowaste: 55 - 65%	70 - 90%	80 - 95%	70 - 80%	10 - 15%
Range of acceptable C:N	20 - 50	20 - 50	10 - 25	16 - 25	Non-influential	Non - influential
Coarse woody material content[1]	Inert	Inert	Inert	Inert & risks[2]	Inert	Good feedstock

With the values of Table 38 and the information you have already obtained regarding the waste collected/generated and waste type (Table 17), you can estimate the suitable fraction of waste for each treatment technology. If you add new technology alternatives to your list, you will first have to gather the characteristics of the biowaste that are required for it to be treatable.

Step 5

The attribute "treatment capacity" (T) is calculated using Equation 13:

Equation 13

$$T_x (\%) = \frac{\textit{Waste amount suitable for technology X}}{\textit{Total collected orgenerated amount of waste}}$$

Example to calculate objective "high treatment capacity"

Assume the biowaste collected in a given case study consists of the following fractions as shown in Table 39

Table 39: Example – biowaste fractions collected in a case study

Biowaste fractions	Current use/final disposition	Amounts	Unit	Variations
Cocoa shells	Disposed	251	kg/week	–
Coconut husks	None	-	-	–
Wood material	Disposed	57	kg/week	–
Reed baskets	Reused	-	-	–
Grass clippings	Disposed	32	kg/week	–
Vegetable waste	Disposed	116	kg/day*	–
Fruit waste	Disposed	95	kg/day*	–
Fish waste	Animal feed	-	-	–
Meat waste	Animal feed	-	-	–
TOTAL WASTE		2,025	kg/week	–

**Note that the unit for vegetable waste and fruit waste is not the same. In order to compute the total amount, first the units of these two need to be converted into per week (multiply by 7).*

Now, from the different types of wastes that we have, we check how they score for the three study parameters: moisture, C:N and woody content. Make sure you obtain data as accurately as possible. When no local data is available, you can consult the database provided in the Annex 2. Only the wastes that are disposed of should be evaluated.

Table 40: Example - characterisation of the collected biowaste

Biowaste fractions	Moisture (%)	C(%db)	N(%db)	C:N	Woody
Cocoa shells	8	50.6	2.3	22:1	Yes
Coconut husks	-	-	-	-	-
Wood material	10	50.4	0.09	560:1	Yes
Reed baskets	-	-	-	-	-
Grass clippings	82	57.8	3.4	17:1	No
Vegetable waste	87	51.3	2.7	19:1	No
Fruit waste	80	56	1.4	40:1	No
Fish waste	-			-	-
Meat waste	-			-	-

db: dry basis

Now, it is time to check which technology could be used to treat each waste. We compare the values from Table 40 with the ones given in Table 38. We distinguish between three different colour codes:

- Green: the waste is suitable for this treatment technology without any pretreatment
- Red: the waste is not suitable
- Yellow: it could be suitable if mixed with other fractions or by adapting the moisture content to achieve the targeted characteristics.

Table 41: Example – adequacy of each treatment technology for its biowaste fraction

Biowaste fractions	Amount (kg/ week)	Windrow Composting	In-vessel composting	Vermi-compost-ing	AD	BSF	Slow Pyrolysis
Cocoa shells	251						
Coconut husks	-	-	-	-	-	-	-
Wood material	57						
Reed baskets	-	-	-	-	-	-	-
Grass clippings	32						
Vegetable waste	812						
Fruit waste	665						
Fish waste	-	-	-	-	-	-	-
Meat waste	-	-	-	-	-	-	-
TOTAL WASTE	1,817	1,817	1,817	1,509	1,509	1,509	308

From this example, we see that the composting technologies would require mixing the "dry" and "wet" materials. In this case, we see that the "dry" materials (coconut shells, coconut husks and wood) amount to 516 kg/week, whereas the wet materials (grass clippings, vegetable waste and fruit waste) amount to 1,509 kg/week. Here, we should be careful to ensure that the mix achieves the targeted feedstock characteristics for composting. Equation 7 can be used to determine the C:N of the mix.

$$C{:}N = \frac{251\cdot 50.6\cdot(100-8)+57\cdot 50.4\cdot(100-10)+32\cdot 57.8\cdot(100-82)+812\cdot 51.3\cdot(100-87)+665\cdot 56\cdot(100-80)}{251\cdot 2.3\cdot(100-8)+57\cdot 0.09\cdot(100-10)+32\cdot 3.4\cdot(100-82)+812\cdot 2.7\cdot(100-87)+665\cdot 1.4\cdot(100-80)}\cdot = 26.8{:}1$$

The final C:N of the mix fits within the ranges required for composting; therefore, the mix of the available fractions could be used for composting. If this was not the case, we could take any of the following approaches:

- If you are missing C-rich materials, you could a) try to see if there are any other C-rich wastes available that you did not identify so far, b) reduce the amount of N-rich biowaste fraction considered until you get an adequate C:N range.
- If you are missing N-rich materials, you would do the opposite.

If you add or reduce biowaste fractions, the amount of the waste you are treating will change. This final amount is the value you should consider when calculating the value of the attribute "percentage of total collected biowaste that can be treated by the technology". For a total amount of 1,817 ton/week as shown in Table 41, these are the amounts and the corresponding "treatment capacities" to be evaluated for each technology:

Table 42: Example – final treatment capacities per technology

Biowaste fractions	Windrow Composting	In-vessel composting	Vermi-composting	AD	BSF	Slow Pyrol.
Total treatable waste (kg/week)	1´817	1´817	1´509	1´509	1´509	308
Treatment capacity (% of total waste collected)	100%	100%	83%	83%	83%	17%

CSF – CASE STUDY

In Annex 1, Table 88 presents the amounts of different biowaste fractions generated during six months. This waste was considered the target biowaste for the assessment since it is already collected and brought to the landfill. Table 43 presents the averages and standard deviations of the data from the six months.

Table 43: Average monthly collected amounts of biowaste fractions in CSF

Biowaste fractions	Current use	Amount (ton/month)	Variation (s.d.)
Banana peelings (market)	Sold in market	1.7	±0.3
Biodegradable (brgys)	Landfill	13.7	±6.9
Biodegradable (city)	Landfill	3.5	±3.5
Biodegradable (private haulers)	Landfill	0.8	±1.9
Coconut meat (market)	Sold in market	1.6	±0.3
Coconut shell (brgy)	Landfill	0.9	±1.1
Coconut shell (city)	Landfill	45.7	±3.3
Dried Coconut shell (market)	Sold in market	3.4	±0.8
Fish entrails (market)	Sold in market	2.4	±0.2
Food scrap	Landfill	2.5	±1.4
Market bio	Landfill	7.4	±3.2
Vegetable trimmings (market)	Sold in market	2.4	±0.7
Total (kg)		85.9	

In Table 43, we see that some of these fractions are already sold in the market and, therefore, do not constitute waste since they are reused. Since the goal is not to alter the current reuse practices, we will not include these fractions in our assessment. On the other hand, you will also notice that most of the biowaste fractions going to the landfill vary considerably.

It is important to consider this variability and check if there is a pronounced difference between the characteristics of the waste (moisture content, C:N ratio and wood content) from one season to another. To give an extreme example, imagine that the biowaste generated in your case study is mainly dry and woody during the first half of the year, and moist and green for the rest of the year. This clear distinction implies that you might require two different types of technologies.

In the case of CSF, we see that we have a predominant fraction (Coconut shells - city) which is pretty much constant (small s.d.) and, therefore, we will not make this distinction.

Let us now have a look at the waste properties of the unused biowaste fractions. Table 43 has been simplified into Table 44, following the next steps:

1. Discard the biowaste fractions that are sold in the market
2. Cluster the remaining biowaste types based on their properties. In this case, only two waste fractions were identified:
    a. "Food and garden waste": Biodegradable waste, food scrap and market biowaste
    b. Coconut shells
3. Total the amounts and assess their properties, using the database in (Annex 2).
    a. Food and garden waste are assumed to have similar properties as organic domestic waste.

Table 44: Characteristics of available biowaste in CSF

Biowaste fractions	Amount (ton/ month)	Amount (kg/day)	Moisture (%)	VS(%)	C(%db)	N(%db)	C:N	Woody
Food and garden waste	27.9	930	55	80	39.6	1.75	22.6	No
Coconut shell	46.6	1'550	5.6	76.1	52.3	0.3	174:1	Yes
Total (kg)	74.5	2'480						

Let's now assess the suitability of the biowaste fractions for each technology. Use the values shown in Table 38 in Step 5, section "High treatment capacity". Remember the colour coding:

- Green: the waste is suitable for this treatment technology without pretreatment
- Red: the waste is not suitable
- Yellow: it could be suitable if mixed with other fractions to achieve the target feedstock characteristics.

Table 45: Suitability of the biowaste fractions in CSF for each technology

Biowaste fractions	Windrow Composting	In-vessel composting	Vermi-composting	AD	BSF	Slow Pyrolysis
Food and garden waste	Yellow	Yellow	Yellow	Yellow	Yellow	Red
Coconut shells	Yellow	Yellow	Red	Red	Red	Green

Step 5

From the suitability assessment, we conclude:

- The food and garden waste could be suitable for windrow composting, in-vessel composting, vermicomposting, anaerobic digestion and BSF processing; however, it will require an increase in moisture. The moisture content value in this case is taken from a database; therefore, it is recommended to analyse the moisture content of several real samples. Slow pyrolysis will be discarded due to the moisture content, which is too high.

- The C:N of food and garden waste is 22, close to the maximum recommended value for vermicomposting and anaerobic digestion (Max C:N = 25). Therefore, we will only consider the amounts of food and garden waste for these two treatment technologies.

- Food and garden waste would have to be dried considerably for them to be treatable by slow pyrolysis. Therefore, this feedstock will not be considered for this technology.

- Coconut shells are considered inert material in the BSF treatment process. Therefore, we do not consider this feedstock as adequate for BSF treatment.

- Coconut shells would be an excellent feedstock for slow pyrolysis. It could be an adequate feedstock if mixed with moist and nitrogen-rich biowaste. It will not be suitable for vermicomposting, anaerobic digestion or BSF processing.

Now, check the final C:N and moisture content of the mix, using Equation 6 and Equation 7, respectively.

$$Moisture = \frac{Mass\ of\ water}{Total\ mass} = \frac{27.9 \cdot \frac{55}{100} + 46.6 \cdot \frac{5.6}{100}}{2.9+46.6} \cdot 100 = 24.1\%$$

$$C:N = \frac{27.9 \cdot 39.6 \cdot (100-55) + 46.6 \cdot 52.3 \cdot (100-5.6)}{27.9 \cdot 1.75 \cdot (100-55) + 46.6 \cdot 0.3 \cdot (100-5.6)} \cdot = 79.6:1$$

We conclude that the C:N is too high and the moisture content too low for windrow composting and in-vessel composting . Since moisture can be fixed by adding water, we will work on the C:N to estimate what is the maximum amount of coconut shells that we could mix with the biowaste and still get a C:N lower than 50 (max acceptable value of C:N for composting).

$$C:N = \frac{27.9 \cdot 39.6 \cdot (100-55) + X \cdot 52.3 \cdot (100-5.6)}{27.9 \cdot 1.75 \cdot (100-55) + X \cdot 0.3 \cdot (100-5.6)} \cdot < 50:1 \rightarrow X?$$

We conclude that X needs to be equal or smaller than 17 ton/month, or 570 kg/day. Only then, can we get a C:N <50:1 and have an adequate feedstock for composting.

Therefore, the treatment capacity table will look like Table 46.

Table 46: Treatment capacity of each technology for the biowaste fractions generated in CSF (kg/day)

Biowaste fractions	Waste collected	Windrow Composting	In-vessel composting	Vermi-compost-ing	AD	BSF	Slow Pyrol.
Food and garden waste	930						
Coconut shells	1'550						
Total	2'480	930+570= 1'500	930+570= 1'500	930	930	930	1'550
Treatment capacity	100%	60.5%	60.5%	37.5%	37.5%	37.5%	62.5%

For the case of CSF, half of the technologies will handle around 1 ton of biowaste (930 kg) and the other half around 1.5 tons. Consequently, whenever an objective makes the difference between self-use and commercial scale, the properties of commercial scale plants were considered.

HIGH JOB CREATION

This objective is measured by the attribute "Number of workers needed per ton of waste treated per working day". The unit of measurement is, therefore, worker per ton and working day.

Attribute	Unit
Number of workers needed per ton of waste treated per working day	$\frac{\text{N° workers employed}}{\textit{ton} \cdot \textit{working day}}$

In order to compute the values for this attribute, we first need to have calculated the values for the sub-objective "high treatment capacity" for each technology. Once we know how much biowaste could be treated in each technology, we can estimate the number of jobs that would be created. Table 47 provides two possible values depending on the amounts of waste. Amounts smaller than 1 ton per day can be managed by one operator. For amounts bigger than one ton, more operators are required. From experience, we have seen that some treatment plants are meant to provide a lot of employment and, therefore, tend to be overstaffed. Here, our goal is to provide flexibility to decide if job creation is favoured or not and, therefore, the table provides a range (keep in mind that a higher number of workers also implies higher operational costs, as explained in the section "high economic feasibility, in Step 5). The smaller figure is the adequate number of operators required for each additional ton treated per day. The bigger figure shows the highest number of workers identified in overstaffed installations.

Table 47: Number of workers needed for each technology

	N° of workers		Reference
	<1 ton/day	>1 ton/day (workers per 1 ton/day)	
Windrow Composting	1 - 2 worker	1 - 2.5	(Harper et al., 2004) (SWAPP, 2009)
In-vessel composting	1 worker	1 - 2	(SWAPP, 2009)
Vermi composting[1]	1 - 2 worker	1 - 2	(SWAPP, 2009)
Anaerobic digestion	1 worker	1 - 2	(Vögeli et al., 2014)
BSF[2]	3 workers	1 - 2 and an additional worker every 5 tons	(Diener, 2016)
Slow Pyrolysis[3]	3 - 5 workers per ton/day	More installations	(GSO, 2014) (Pfyffer, 2016) (CIDA et al., 2011)

[1] A windrow composting plant or vermicomposting plant treating between 0.5 – 1 ton could have more than 90 tons of total mass to be handled considering a processing time of around 3 – 5 months. For these amounts we recommend 2 workers. Amounts less than 0.5 tons/day could be handled by 1 worker.

[2] A BSF installation treating less than 1 ton/day, requires 2 workers for the larvae production and 1 worker to handle the waste. For bigger amounts, 1 – 2 workers are needed to handle every additional ton of waste, plus 2 extra people are needed for every additional 5 tons to produce the larvae.

[3] The maximum treatment capacity of the slow pyrolysis technologies studied ranged between 240 and 550 kg of feedstock per day. If more waste needs to be treated per day, more installations need to be built (increasing the investment and operational costs). All other technologies could be designed to the required capacity.

Table 47 only shows the number of workers required to operate the technology when it comes to activities, such as loading, unloading, turning, bagging, etc. If the treatment facility is meant to become an enterprise, you might want to include some of the following positions, which should be added on top of the computed figures from Table 47.

- General manager
- Accountant
- Production supervisor
- Marketing expert
- Maintenance staff

In case you add a new technology alternative, these are the steps and the information required to calculate the number of workers per ton of biowaste per day:

- Total amount of waste treated per day at the facility with this specific technology. This can also be derived from the yearly waste treatment capacity of the facility divided by the number of working days.
- Total number of workers employed at this same facility per day.

With this information, the attribute with its right unit (worker/tons per working day) can be calculated. Below, is the explanation of how to do this:

Example 1:

Suppose you determine the following information about an in-vessel composting plant:

- The technology treats 10´800 tons of waste per year
- There are 45 workers in the plant

1. The first thing you should check is how many working-days per year there are in your case study.

Let us assume that there are 260 working days per year

2. Now, calculate how many tons of waste are treated per working day.

Required information:

- 10´800 tons are treated in a year
  - There are 260 working days per year

Calculation:

$$10'800 \frac{\text{tons}}{\text{Year}} \cdot \frac{1 \text{ year}}{260 \text{ working days}} = \frac{10'800 \text{ tons}}{260 \text{ working days}}$$

=41,5 tons of waste are treated per working day

3. Now, calculate how many workers are needed per ton.

$$45 \frac{\text{workers}}{\text{working day}} \cdot \frac{1 \text{ working day}}{41.5 \text{ tons}} = \frac{45 \text{ workers}}{41.5 \text{ tons}} = 1.08 \text{ workers per ton ot waste}$$

Here, we recommend to always round up this value. Always consider full or half units. Therefore, in this case, we would need 1.5 workers per ton per working day.

Example 2:

Now, suppose you determine the following information about a vermicomposting plant:

- One worker can treat 400 kg of waste per hour

This same worker works eight hours per day and, therefore, could treat 2´400 kg of waste in one day.

Calculating how many workers are needed per ton can be done as follows:

$$\frac{1 \text{ worker}}{2.4 \text{ tons}} = 0.42 \approx 0.5 \text{ workers per ton of waste per day}$$

Example 3:

Let us assume that we have seven tons of biowaste per day. After checking the sub-objective "high treatment capacity", we see that windrow composting could treat 100% of this waste. We then checked the number of workers needed per ton of waste treated per day: 1 - 2.5.

$$\text{Lower end: } 7\ \text{ton/day} \cdot 1 \frac{\text{worker}}{\text{tons/day}} = 7\ \text{workers}$$

$$\text{Higher end: } 7\ \text{ton/day} \cdot 2.5 \frac{\text{worker}}{\text{tons/day}} = 17.5 \approx 18\ \text{workers}$$

The decision maker could choose between a value that ranges between 7 and 18 workers. Let us say they opt to hire seven operators since they want to lower their operational costs. Besides, the decision makers are planning to run this treatment facility as an enterprise; in addition to the operators, they will hire a manager, an accountant and a marketing expert. That means 7 + 3 = 10 jobs created.

This operation would have to be repeated for each technology, considering the biowaste amounts suitable for each.

CSF –CASE STUDY

Table 48 shows the amounts of each biowaste fraction obtained in the previous exercise. These are the amounts that can be treated by each technology for the case of the City of San Fernando. We will convert these values first to ton/day and then multiply by the number of workers needed shown in Table 47.

Table 48: Amounts of biowaste fractions treatable by each technology in CSF

	Windrow Composting	In-vessel composting	Vermi-composting	AD	BSF	Slow Pyrol.
Total (ton/month)	44.9	44.9	27.9	27.9	27.9	46.6
Total (ton/day)	1.5	1.5	0.9	0.9	0.9	1.6
N° workers needed	2 - 4	2 - 3	1	1	3	3 - 5

Since we are dealing with around one ton of waste per day, we assume that the installation will not be profit-oriented and, therefore, there is no need to hire additional staff, such as a general manager, an accountant, a production supervisor, a marketing expert or maintenance staff. This way, the operation costs (salaries) will also be kept lower.

Windrow composting, in-vessel composting and slow pyrolysis have a minimum and a maximum number of workers that would be needed. In this case, for the sake of keeping operational costs low, the required minimum number of workers will be chosen.

HIGH TECHNICAL RELIABILITY

This objective is measured by the attribute "cumulative number of downtime days per year". The unit of measurement is, therefore, days/year.

Attribute	Unit
Cumulative number of downtime days per year	Days/year

The long-term technical functionality of a treatment plant is a crucial aspect of sustainability. By this, we mean that treatment plants should be as resilient and robust as possible so that they can keep operating and treating waste. However, we know from experience that this is often not the case. Below, we noted the four most common factors that typically influence the time of consecutive days when a treatment technology is out of service:

- Availability and affordability of water
- Availability and affordability of energy (fuel or electricity)
- Availability and affordability of equipment and spare parts
- Availability and affordability of skilled staff

If any of these factors is not ensured, a technology could stop its operation and, consequently, will not be able to treat the incoming waste. That leads us to the attribute that will be considered for this objective: cumulative number of downtime days per year.

The availability and affordability of the four resources mentioned above is entirely context-dependent and needs to be assessed for each particular case. Furthermore, the lack of each resource does not necessarily have the same impact on each technology. For instance, a lack of water will drastically influence the operation of an anaerobic digestion plant, but will not impact the operation of a slow pyrolysis unit.

An interesting and recommended exercise is to check which biowaste treatment technologies were previously implemented in your case study and what happened to them. Check if they are still operating or not, and if not, find out why they failed. This will give you very valuable insights.

In the next section, the requirements for each resource by each technology and the duration that the technology could still operate without this resource will be explained. Later, the questionnaires that will be given to the stakeholders will be introduced, and finally the methodology will get a final score per technology.

WATER NEEDS

All technologies considered in this manual, except for slow pyrolysis, are biological and, therefore, require considerably high moisture contents (60 -95% MC). Depending on the nature of the available biowaste, these moisture content requirements might already be fulfilled, or might have to be achieved by simple pre-treatment methods, such as sun-drying (when they are too moist) or by adding water. Table 49 presents the typical ranges of moisture content required for each technology.

Table 49: Water requirements per technology (from Table 16)

Technology[a]	Water needs		Duration without water
	Input MC	Replenish evaporation loss	
Windrow Composting	Coarse: 70 - 75% Fine: 55 – 65%	5 - 100 L/ton per day[b]	If covered, 14 days otherwise 7 days
In-vessel composting	Coarse: 70 - 75% Fine: 55 – 65%	5 - 60 L/ton per day[b]	7 days
Vermi composting	70 - 90%	5 - 40 L/ton per day[b]	If covered, 7 days Otherwise 3 days
Anaerobic digestion	80 - 95%	Not needed	30 days
BSF	70 - 80%	Not needed	0 days
Slow Pyrolysis	10 - 15%	Not needed	Not needed

[a]There is no distinction between small and large scale plants.
[b]Check Annex 5 if you want to get a more accurate value. Otherwise, consider the average of the values given.

Now, it is time to check on the water availability in your location. Is water always available, considering the values given in Table 49? If yes, you can skip the next pages and move to the next objective. However, if you suspect that it might be hard to supply those amounts constantly throughout the year, or during a particular season (dry season), we recommend that you read the following pages and estimate the water requirements for the considered technologies. This will facilitate times when the technology enters into downtime periods due to the lack of water

How do we calculate the amount of water needed by a technology for a given amount of biowaste? Let us use the following example:

Example

Assume that you generate 50 kg of biowaste per day with a moisture content of 40%. And you think that vermicomposting would be a suitable technology in your case. So, you now want to calculate how much water you need to add to increase the moisture content to 80% (middle point between 70 – 90%). How do you do that?

You first need to know how much water (in mass units) there is in your feedstock

$$Mass_{Water} = Mass_{total} \cdot MC\% = 50\ (kg) \cdot 0.4 = 20 \text{ kg of water}$$

Once you mix this biowaste with water, these 20 kg together with the added amount of water, will represent 80% of your mass (remember that we are targeting a moisture content of 80%!) We could write the following equation, and isolate "X".

Equation 14

$$MC\ (\%) = \frac{Mass_{water}}{Mass_{total}} = \frac{Mass_{input\ water} + Mass_{added\ water}}{Mass_{input\ water} + Mass_{added\ water} + Mass_{total\ solids}}$$

$$MC\ (\%) = 80\% = 0.8 = \frac{20(kg) + X(kg)}{20(kg) + X(kg) + 30\ (kg)} \rightarrow 0.8 \cdot (20 + X + 30) = 20 + X \rightarrow$$

$$40 + 0.8X = 20 + X \rightarrow 40 - 20 = X - 0.8X \rightarrow 20 = 0.2X \rightarrow X = \frac{20}{0.2} \rightarrow X = 100\ kg$$

We could also isolate $Mass_{added\ water}$ in Equation 14 as shown below:

$$Mass_{added\ water} = \frac{MC(\%) \cdot (Mass_{total\ solids} + Mass_{input\ water}) - Mass_{input\ water}}{1 - MC(\%)}$$

Result: 100 kg (or 100 litres) of water will have to be mixed with the 50 kg of feedstock in order to get a moisture content of 80%. That means that you need to ensure that you have access to 100 kg of water every day!

Step 5

We have calculated how to achieve the targeted initial moisture content. But, the process is not finished. The vermicomposting plant has water losses through evaporation, and the worms need a constant moisture content of 70 – 90% to flourish and grow. This means that you will have to add water consistently.

The amount of water losses through evaporation depend on several aspects: temperature in the material, ambient temperature, relative humidity and atmospheric pressure. Table 49 presents default values that you can use to estimate your water demands. If you wish to calculate your water needs in a more accurate way, check the methodology presented in Annex 5.

Now that you can calculate the water requirements per day for all technologies, you need to assess the water availability in the case study. For this, we recommend that you interview several people and ask them the following questions:

- How much water could be supplied per day? Make a X in the next line:

10 L/day	250 L/day	500 L/day	750 L/day	1000 L/day

*Adapt the amounts shown on this line according to your needs.

- What would be the longest period of time that water needs cannot be satisfied (due to a delay in the delivery, dry season, shortcuts or due to lack of budget) assuming you do not have storage?
- What happens if there is no sufficient water?

With the first question, we will know if we can supply the required water for the biowaste treatment. In case there is no water, the technologies can last a couple of days or even weeks. These periods are shown in Table 49. But, water will be required at one point and unless you supply it or it rains, the technology will stop its operation. The answers to the second question will indicate the duration of the lack of water. If these durations are longer than those given in Table 49, the technology will stop operating and will enter a downtime period.

ENERGY NEEDS

The procedure to calculate the energy needs is very similar to the steps explained for the water needs. It is assumed that only the commercial scale plants will require energy in terms of electricity or fuel. Only the energy needs, which are essential to run the treatment technologies, are considered here. Other energy needs (e.g. lighting, heating, cooling, bagging machine, ventilation, etc.) are not included due to large differences between climatic regions and latitudes. Table 50 determines the energy consumptions considered per technology.

What happens if there is no energy? Or, there is a shortage of fuel? Or, a power failure (blackout)? In these cases, the self-use, small scale plants will be less influenced by the shortage of energy as they typically rely on manual labor. However, the commercial scale plants will be non-operational. Table 50 indicates that the technologies will not operate without an energy supply (duration of 0 days). However, fuel could still be supplied, which could also be used to produce electricity with a generator. For this exercise, we assume a worst-case scenario.

Knowing the amounts to be treated, we can now calculate the energy needs per day for all technologies by multiplying the amounts of waste by the energy needs per unit of waste (kWh/ton). This number can then be compared to the energy availability in your case. Keep in mind that energy can be supplied in the form of both fuel and electricity. In case you need electricity for your equipment, both fuel supplies would be valid since you could transform fuel to energy with a generator. In case you need fuel for your equipment, you really need to make sure you have access to fuel. Therefore, when estimating the availability of energy, make sure your questions target the right energy type for your needs.

- **Equipment:**
Providing that you will install commercial-scale infrastructure, it is very advisable to know which types of equipment you will be using beforehand, and whether they will be fuel-based or electricity-based. This knowledge will facilitate answering the following points.

- **Electricity supply network:**
When it comes to electricity supply, we recommend that you interview local electricians. Aspects to take into consideration are:

  - Supply outlets (sockets-plugs)
  - Voltage (V)
  - Maximum allowable current (A)
  - Age and quality of the cables
  - Maximum duration of blackouts

Make sure you check the following questions:

- Can the electricity supply network cope with the demand if all equipment for a given technology is consuming energy at the same time?
- What would be the longest period of time that electricity needs cannot be satisfied due to a blackout?
- What would be the longest period of time that electricity needs cannot be satisfied due to a lack of budget?

The answer to the last two questions will determine the downtime period.

• Fuel supply:
The fuel supply will only be relevant when fuel-based equipment is used. The only aspect that matters is the reliability of fuel supply.

- What would be the longest period of time that fuel needs cannot be satisfied (due to a delay in the delivery or due to a lack of budget) assuming you do not have storage?

The answer to that question will determine the downtime period.

Table 50: Energy needs per technology and resilience level

Technology	Scale	Activity	Energy need (kWh/ton)	Type of fuel	Duration without energy	Reference
Windrow Composting	Self-use	All manually done	0		Not needed	
	Commercial	• Shredder • Skid loader • Sieve	6 - 13.5 25 - 40 1 Total: 32 - 54.5	Fuel/electricity Fuel Fuel/electricity	0 days	(Alibaba, undated) (CAT, undated)
In-vessel composting	Self-use	All manually done	0		Not needed	
	Commercial	• Vessel • Shredder • Skid loader • Sieve	135 6 - 13.5 25 – 40 1 Total: 167 - 190	Fuel/electricity Fuel/electricity Fuel Fuel/electricity	0 days	(GSO, 2014) (Alibaba, undated) (CAT, undated)
Vermi composting	Self-use	All manually done	0		Not needed	
	Commercial	• Shredder • Skid loader • Sieve	6 - 13.5 25 – 40 1 Total: 32 - 54.5	Fuel/electricity Fuel Fuel/electricity	0 days	(Alibaba, undated) (CAT, undated)
Anaerobic digestion	Self-use	All manually done	0		Not needed	
	Commercial	• Shredder • Skid loader	6 - 13.5 25 – 40 Total: 31 – 53.5	Fuel/electricity Fuel	0 days	(Alibaba, undated) (CAT, undated)
BSF	Self-use	All manually done	0		Not needed	
	Commercial	• Shredder • Skid loader • Sieve • Light • Pressurised water • Washing machine • Larvae processing (boiling, pellets)	6 - 13.5 25 – 40 1 1 3 2.5 44.5 Total: 83 – 105.5	Fuel/electricity Fuel Fuel/electricity Electricity Electricity Electricity Fuel/Electricity	0 days	(Alibaba, undated) (Dortmans, 2017) (CAT, undated)
Slow Pyrolysis	Self-use	• Partly combusted • Fuel	• Partly combusted • Fuel	- Fuel	Not needed	
	Commercial	• Shredder • Skid loader • Lambda sensor • Fuel	• Shredder • Skid loader • Lambda sensor • Fuel	Fuel/electricity Fuel Electricity Fuel		(Alibaba, undated) (CAT, undated) (Dortmans, 2017)

Equipment often requires spare parts or additional components to ensure long-term continuous operation. A lack of parts can lead to downtime. Table 51, Table 52 and Table 53 show the essential equipment or material required for each type of treatment technology and the number of days that the technology can cope without this piece of equipment or its spare parts. If the equipment or material is not repaired within that period of time, the technology stops operating properly; the time when equipment is not functioning fully is considered downtime. For a detailed list of equipment needed for each technology, please refer to the section "Examples of biowaste treatment technologies" in "Part 1. Background".

Table 51: List of essential equipment per technology and maximum number of operation days without equipment: windrow composting & in-vessel composting

	Windrow composting				In-vessel composting			
	Self-use		Commercial		Self-use		Commercial	
	Items	**N° days**	**Items**	**N° days**	**Items**	**N° days**	**Items**	**N° days**
1	Bucket or water hose	120	Bags	60	Bucket or water hose	120	Bags	60
2	Cover material[1]	120	Bucket or water hose	120	Knife (or alike)	0	Bucket or water hose	120
3	Knife (or alike)	0	Cover material or roofing	120	Shovel (or alike)	0	Record keeping material[2]	30
4	Shovel (or alike)	0	Front loader or Compost turner / Shovel or Fork	0	Vessel container	0	Shovel (or alike)	0
5	Wheel barrow (or alike)	0	Record keeping material[2]	30	Wheel barrow (or alike)	0	Shredder	0
6			Shredder	0			Sieve	0
7			Sieve	0			Thermometer	30
8			Thermometer	30			Vessel container	
9			Wheel barrow or small truck	0			Wheel barrow or small truck	0

[1]Cover materials. Examples: plastic sheets, fibres, etc.
[2]Record keeping material. Examples: monitoring sheets, pens, folders, etc.

Table 52: List of essential equipment per technology and maximum number of operation days without equipment: vermicomposting & Black Soldier Fly

	Vermicomposting				Black Soldier Fly			
	Self-use		Commercial		Self-use		Commercial	
	Items	N° days	Items	N° days	Items	N° days	Items	N° days
1	Ant traps	30	Ant traps	0	Ant traps	30	Ant traps	0
2	Bedding material	60	Bags	60	Containers with lids	0	Bags	0
3	Containers / worm bed (concrete, plastic, etc.)	0	Bedding material	60	Knife (or alike)	0	Bedding material	only once
4	Cover material[1]	0	Bucket or water hose	0	Larvae	only once	Buckets	2
5	Knife (or alike)	0	Cover material[1]	0	Shovel (or alike)	0	Containers	0
6	Shovel (or alike)	0	Flooring and bed structure (concrete, bricks, etc.)	0	Wheel barrow (or alike)	0	Larvae	0
7	Wheel barrow (or alike)	0	Record keeping material[2]	30			Light	30
8	Worms	only once	Scale	0			Nets (love and dark cage)	0
9			Shovel (or alike)	0			Oviposition material	0
10			Shredder	0			Record keeping material[2]	0
11			Sieve	0			Roofing (closed room)	0
12			Wheel barrow or small truck	0			Scale	0
13			Worms	only once			Shovel (or alike)	30
14							Shredder	0
15							Sieve	0
16							Washing machine facility	0
17							Wheel barrow / Bucket / small truck	only once

[1] Cover materials. Examples: plastic sheets, fibres, etc.

[2] Record keeping material. Examples: monitoring sheets, pens, folders, etc.

Table 53: List of essential equipment per technology and maximum number of operation days without equipment: anaerobic digestion & slow pyrolysis

	Anaerobic digestion				Slow pyrolysis			
	Self-use		Commercial		Self-use		Commercial	
	Items	N° days	Items	N° days	Items	N° days	Items	N° days
1	Buckets	0	Bucket or water hose	0	Building material [2]	0	Bags	60
2	End gas use with valve (stove)	1	Gas end-use (gas generator or stoves)	0	Burners[3]	0	Building material [2]	0
3	Gas pipes and tubes	1	Gas pipes and tubes	0	Fuel[4]	0	Burners[3]	0
4	Knife (or alike)	0	Reactor (different types)	0	Knife (or alike)	0	Fuel[4]	0
5	Reactor (different types)	0	Record keeping material[1]	30	Oil barrels	0	Lambda sensor	0
6	Repair kit	120	Repair kit	120	Wheel barrow (or alike)	0	Oil barrels	0
7	Unblocking device (feeding) (Stick)	7	Scale	0			Record keeping material[1]	30
8	Water trap	7	Shredder	0			Shredder	0
9			Unblocking device (feeding) (Stick)	7			Thermocouples	0
10			Valves	0			Wheel barrow (or alike)	0
11			Water trap	7				
12			Wheel barrow (or alike)	0			Scale	0

[1] *Record keeping material. Examples: monitoring sheets, pens, folders, etc.*
[2] *Building materials for furnace, reactor and chimney: bricks, cement, metal sheets, metal bars*
[3] *The need for a burner and the type of burner depends on the technology*
[4] *The fuel used depends on the technology*

In order to calculate the number of downtime days caused by lack of equipment or material, follow the following steps:

1. Have a look at the list of items needed for the first technology of interest
2. Assess if the items mentioned can easily be repaired, replenished or substituted in your case study
3. Identify the item that seems most difficult to repair, replenish or substitute
4. Estimate how many days would be needed to repair, replenish or substitute it
5. If the number of days is longer than the number of days given in the tables, calculate the difference. This will be considered as the downtime period.
6. Repeat the same process for the other technologies to estimate the downtime periods caused by lack of equipment.

NEED FOR SKILLED STAFF

A lack of required operational and maintenance skills is another determining factor of success. This is a factor that has often been neglected, especially with charity-based donated infrastructure, which often breaks down and remains unrepaired. Consequently, well-trained staff is a critical factor for long-term success. All the skills required to run these technologies are summarised according to the following seven types:

1. Basic knowledge of biology of the decomposition process
2. Basic knowledge of the biology of worms & insects
3. Basic knowledge of combustion processes
4. Driving heavy machinery
5. Basic marketing and sales experience
6. Knowledge of electrical / electronical control systems
7. Qualified mechanic to maintain technical parts

Some of these skills are more specialised than others and, therefore, more difficult to find people who have mastered them. Some of the skills can also be learnt in a short amount of time and are, thus, not so limiting. In Table 54, we see the skills required for each technology. The table also indicates the duration that the technology can operate under three scenarios: 1) there is no skilled staff or they are often absent, 2) the skilled staff is not physically present, but can be reached by phone or email and 3) the skilled staff is physically present when required.

Table 54: Skills needed per technology and number of days the technology can operate without them

Technology		Skills needed	N° days in operation		
Type	**Scale**		**Non existent**	**Reachable (phone, e-mail)**	**Available if required**
Windrow Composting	Self-use	1) basic knowledge of biology of the decomposition process	0 days	Not a problem	Not a problem
	Commercial	1) basic knowledge of biology of the decomposition process 2) driving heavy machinery 3) basic marketing and sales experience 4) qualified mechanic to maintain technical parts	0 days	a) Not a problem b) 0 days c) 30 days d) 0 days	Not a problem
In-vessel composting	Self-use	1) basic knowledge of biology of the decomposition process 4) qualified mechanic to maintain technical parts	0 days	a) Not a problem b) 0 days	Not a problem
	Commercial	1) basic knowledge of biology of the decomposition process 2) driving front-end loaders 3) basic marketing and sales experience 4) qualified mechanic to maintain technical parts 5) knowledge of electrical / electronical control systems	0 days	a) Not a problem b) 0 days c) 30 days d) 0 days e) 0 days	Not a problem
Vermi composting	Self-use	1) basic knowledge of biology of the decomposition process 6) basic knowledge of the biology of worms and insects	0 days	a) Not a problem b) 14 days	Not a problem
	Commercial	1) basic knowledge of biology of the decomposition process 3) basic marketing and sales experience 6) basic knowledge of the biology of worms and insects	0 days	a) Not a problem b) 14 days c) 30 days	Not a problem
Anaerobic digestion	Self-use	1) good knowledge of biology of the decomposition process 4) qualified mechanic to maintain technical parts	0 days	a) 7 days b) 7 days	Not a problem
	Commercial	1) good knowledge of biology of the decomposition process 3) basic marketing and sales experience 4) qualified mechanic to maintain technical parts	0 days	a) 7 days b) 7 days c) 30 days	Not a problem
BSF	Self-use	1) basic knowledge of biology of the decomposition process 6) good knowledge of the biology of worms and insects	0 days	a) Not a problem b) 14 days	Not a problem
	Commercial	1) basic knowledge of biology of the decomposition process 3) basic marketing and sales experience 6) good knowledge of the biology of worm and insects	0 days	a) Not a problem b) 14 days c) 30 days	Not a problem
Slow Pyrolysis	Self-use	4) qualified mechanic to maintain technical parts 7) basic knowledge of combustion processes	0 days	a) 0 days b) 0 days	Not a problem
	Commercial	3) basic marketing and sales experience 4) qualified mechanic to maintain technical parts 5) knowledge of electrical / electronical control systems 7) basic knowledge of combustion processes	0 days	3) 14 days 4) 0 days 5) 0 days 7) 0 days	Not a problem

Now, it is time for the field assessment. Once more, the person in charge needs to assess if the required skills are locally available, or if training for these skills can be obtained locally. In order to estimate the period of downtime, the steps to follow are:

1. Have a look at the list of the seven skills needed

2. Assess if the skills are locally available, physically present or not available at all one by one and by checking the interviews.

If they are not available and there is no means of training the staff in that particular skill, the technologies requiring that skill will have a maximum downtime (365 days per year).
If the skills are not available, but training can be easily ensured to the required level, then this skill can be assumed to be available.

If the skills are available, but are not constantly physically present, then consider the following questions:

- What is the longest period of time that the skilled personal will be absent during a year?
- Is there anybody else with these skills who could substitute for this person?

Providing that no other person can substitute for this skilled staff member, but that the skilled person can be reached by email or phone:

3. Write down the longest period of time when the staff will be absent
Choose one of the treatment technologies and have a look at the column entitled "reachable (phone, email)". If the number of days is longer than the number of days given in Table 55, calculate the difference. This will be considered the downtime period caused by the lack of a given skillset.

4. Repeat the same procedures for all skills needed for that technology

5. You will now total all the downtime periods obtained to calculate the aggregated downtime period caused by lack of skilled personnel (note that by summing them up, we are calculating a conservative value)

6. Repeat the same process for the other technologies

How do we calculate the final aggregated technical reliability value? Or the total downtime time? So far, you have calculated that each technology can have a downtime period due to four factors: water, energy, equipment and spare parts, and skilled staff. Now, calculate an aggregated downtime period for each technology. We recommend that you calculate a conservative value, in order to show the worst-case scenario. This would happen if all the calculated downtime periods happen one after another. This accumulated downtime can be calculated by summing up all downtime periods estimated for the four factors for each technology. Table 55 indicates how this aggregated value can be calculated.

Table 55: Calculation of aggregated downtime

Technology	Scale	N° days downtime per aspect				Total downtime
		Water	Energy	Equipment & spare parts	Skilled staff	
Windrow Composting	Self-use	7	0	0	0	7
	Commercial	14	7	7	0	14 + 7 + 7 = 28
In-vessel composting	Self-use	7	0	14	0	7 + 14 =21
	Commercial	30	7	60	0	30 + 7 +60= 97

The total longest downtime represents the longest overlapping period of time (in days) throughout the year when the treatment facility would not be in service and, therefore, would not be able to process any waste. The higher this number, the less this treatment technology is considered reliable and robust.

CSF – CASE STUDY

Let us now assess the technical reliability of the treatment technologies for the case of the City of San Fernando.

In Table 56, the water demands are calculated. The City of San Fernando is a rain-fed area with few water sources except rain. There is no river or aquifer in the vicinity of the city. Rain patterns are estimated to change and the amounts are expected to reduce in the coming years. Water shortages are predicted to occur during the dry season. Therefore, the price of drinking water is also estimated to increase in the future. In spite of the risk of shortages being low, a period of one month was considered to be the longest possible time without a water supply.

Table 56: Calculations of water needs for CSF (L/day)

	Windrow Composting	**In-vessel composting**	**Vermi-composting**	**AD**	**BSF**	**Slow Pyrol.**	**Source**
Waste collected (kg/day)	1'500	1'500	930	930	930	1'550	Table 46
Input MC (%)	36.3%[a]	36.3%[a]	55%[b]	55%[b]	55%[b]	5.6%[b]	a: Equation 6 b: Table 44
Required input MC(%)	70 - 75%	70 - 75%	70 - 90%	90%	70 - 80%	10 - 15%	Table 16
Required water (L/day)	1'970	1'970	1'160	3'500	740	120	Equation 14
Evapotransp. loss	190	80	90	0	0	0	Calculated from Table 49
Total water needs (L/day)	2'160	2'050	1'250	3'500	740	120	-
Duration without water	1 week (not covered)	1 week	3 days (not covered)	1 month	0 days	Not needed	Table 49
Downtime	23 days	21 days	27 days	0	30 days	0	-

Step 5

Electricity and fuel are always available in the City of San Fernando. In the most unlikely event (e.g. a typhoon), the electricity supply can stop for one week.

As for equipment and spare parts, all material can be purchased locally. The spare part that would take longest to be delivered would be a commercial scale in-vessel container, which would take one month.

At the time of the research, there were no experienced people skilled in operating a BSF processing technology. However, the CENRO and GSO representatives argued that the staff is capable of receiving training and of learning. Nevertheless, since BSF is the most challenging technology when it comes to skills required, chances are high that it would suffer from downtimes more often than the others. A downtime of 30 days was assigned to BSF processing.

Table 57 shows the summary of the downtime periods for each of the four aspects:

Table 57: Calculation of total downtime of each technology in CSF

Downtime aspects	Windrow Composting	In-vessel composting	Vermi-composting	AD	BSF	Slow Pyrol.
Water	23 days	23 days	27 days	0	30 days	0
Energy	0	0	0	0	0	0
Equipment and spare parts	0	30 days	0	0	0	0
Skilled staff	0	0	0	0	30 days	0
Total	23 days	53 days	27 days	0 days	60 days	0 days

BSF is the technology that performs weakest for the objective of technical reliability, followed by the composting technologies. Anaerobic digestion and slow pyrolysis are not expected to suffer from downtime for the aspects considered.

LOW EMISSION GENERATION

This objective is measured by the attribute "Amount of CO_2 equivalents emitted per day". The unit of measurement is, therefore, kg CO_2 equivalents/day.

Attribute	Unit
Amount of CO_2 equivalents emitted per day	kg CO_2 equivalents/day

Biowaste treatment reduces environmental pollution by diverting organic waste from dumpsites or landfills. However, during the degradation processes, substances and/or gases may be released and pollute the environment. Among the list of potential environmental impacts, climate change through greenhouse gas emissions is an important threat.

Climate change is defined as a change in the atmosphere's composition that is directly or indirectly attributed to human activity. This is caused by the release of Green House Gas (GHG) emissions to the atmosphere. GHGs are characterised by their ability to absorb infrared light, thus, contributing to an increase in temperature of the atmosphere. The impact of GHGs is evaluated by their Global Warming Potential (GWP). GWP is a relative measure of how much heat a greenhouse gas traps in the atmosphere; it compares the amount of heat trapped by a certain mass of gas to the amount of heat trapped by a similar mass of carbon dioxide. In this way, GHG emissions (in kg) can be converted to their equivalent amount of CO_2 (in kg).

The main three GHG are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Details on GHG GWP and production pathways are found in Table 58.

Table 58: GHG - Global warming potential and production pathways

Gas	Environmental impact
CH_4	**High global warming potential** (27.8 times more than CO_2 considering a time span of 100 years) (IPCC 2013, v1.03) Methane is produced under strictly anaerobic conditions by various methanogenic microorganisms decomposing easily degradable organic compounds.
N_2O	**High global warming potential** (265 times more than CO_2 considering a time span of 100 years) (IPCC 2013, v1.03) The biological production of N_2O is a complex process that relies on various microbial pathways. Among these processes, the most significant are nitrification and denitrification, occurring under aerobic and short-term O_2 limitationed conditions, respectively (Ermolaev et al., 2015; Sánchez et al., 205; Wang et al., 2017).
CO_2	**Reference measure for global warming potential** (1 X CO_2) CO_2 is produced from the decomposition of organic matter and cellular respiration. In organic waste treatment, CO_2 is considered "carbon neutral" as it represents the natural emission from degrading organic matter (Christensen et al., 2009).

The GWP values for methane and nitrous oxide in CO_2 equivalents are 27.8 kg CO_2/kg CH_4 and 265 kg CO_2/kg N_2O, respectively, considering a time span of 100 years, according to the methodology presented in IPCC 2013 (v1.03).

In order to calculate the total CO_2 equivalents emitted per treatment technology, the amount of biowaste to be treated needs to be known. Table 59 shows the amounts of CH_4 and N_2O emitted per ton of biowaste treated per treatment technology. Using Equation 15, the total amount of CO_2 equivalents can be computed.

Equation 15

$$Total\ CO_{2_{equiv}} = GWP_{CH_4} \cdot M_{CH_4}\ (kg) + GWP_{N_2O} \cdot M_{N_2O}\ (kg)$$

$$= 27.8\ \frac{Kg_{CO_2}}{Kg_{CH_4}} \cdot M_{CH_4}\ (kg) + 265\ \frac{Kg_{CO_2}}{Kg_{N_2O}} \cdot M_{N_2O}\ (kg)$$

Step 5

Table 59: Approximate CH_4 and N_2O emissions per technology

Technology	Description	CH_4	N_2O	Ref.	CO_2 equivalent (Equation 15)
Windrow Composting	The emissions generated in composting vary widely depending on the feedstock type, moisture content, aeration mode and overall management. Ranges as wide as 30 – 6'800 g CH_4/kg of wet biowaste and 7.5 – 252 N_2O/kg of wet biowaste have been reported. For the sake of simplification, we will use the values recommended in the Clean Development Mechanisms CDM manual.	2'000 g/ ton (wb)	200 g/ ton (wb)	(Boldrin et al., 2009) (CDM)	108.6 kg/ton (wb)
In-vessel composting	In-vessel composting has been reported to emit much less than windrow composting, in the range of 200 -1'800 g CH_4/ton biowaste (wb) and 10 - 120 g N_2O/ton biowaste (wb).	1'000 g/ ton (wb)	100 g/ ton (wb)	Based on (Boldrin et al., 2009) and (CDM)	54.3 kg/ton (wb)
Vermi composting	In the vermicomposting process, the biowaste is well aerated thanks to the air tunnels dug by the worms. This considerably reduces the production of CH_4 and N_2O as compared to other composting technologies.	40 g/ ton (wb)	10 g/ ton (wb)	(Chan et al., 2011) (Yang et al., 2017)	3.8 kg/ton (wb)
Anaerobic digestion	We consider 0% of CH_4 loss for gas-tight AD digesters, and 3% for all others. The methodology to calculate the amount of methane generated is described in Annex 6. During the AD process there is no N_2O generated.	3% of generated CH_4	-	(CDM, 2012) (Flesch et al., 2011)	
BSF	Similar to vermicomposting, in the BSF treatment process the biowaste is well aerated thanks to the air tunnels dug by the larvae. CH_4 and N_2O emissions are low.	0.4 g/ ton (wb)	8.6 g/ ton (wb)	(Mertenat et al., 2017)	2.3 kg/ton (wb)
Slow Pyrolysis	The level of emissions depends widely on the technology used for the production, the temperature developed during the pyrolysis, as well as on the moisture content and nature of the wood. Reported values include 25 – 83 g CH_4/kg of produced charcoal for non-retort kilns, 7 – 41 g CH_4/kg charcoal for retort kilns and 0.15 g N_2O/kg charcoal. The values given here assume a biowaste to char conversion rate of 35%	Non-retort: 19'600g/ton (db) Retort: 8'500 g/ton (db)	50 g/ton (db)	(Pennise et al., 2001) (Sparrevik et al., 2015)	Non retort: 558 kg/ton (db) Retort : 250 kg/ton (db)

CSF – CASE STUDY

In the section "High treatment capacity" in Step 5, we have calculated the amounts of biowaste to be treated by each technology. Based on those amounts, we can easily calculate the estimated emissions. Some further calculations are required to estimate the emissions from AD. These are shown in Annex 6. Table 60 presents the estimated rough emissions per technology.

Table 60: Estimated kg of CO2 equivalent emitted per day for CSF

Technology	Biowaste amount (kg/day wb)	CO_2 equivalent (kg CO_2/kg biowaste)	CO_2 equivalent (kg CO_2/day)
Windrow Composting	1'500	108.6 kg/ton (wb)	163
In-vessel composting	1'500	54.3 kg/ton (wb)	81.4
Vermi composting	930	3.8 kg/ton (wb)	3.5
Anaerobic digestion[1]	930	3% of generated CH_4	39
BSF	930	2.3 kg/ton (wb)	2.1
Slow Pyrolysis[2]	1'550 (wb), 1'463 (db)	250 kg/ton (db)	365.7

[1] Calculated in Annex 6; [2] Retort kiln is selected.

HIGH ECONOMIC FEASIBILITY

This objective is measured by the attribute "Ratio of income to expenditures of a treatment technology". There is, therefore, no unit of measurement.

Attribute	Unit
Ratio of income to expenditures of a treatment technology	-

In this manual, we suggest a simple approach to calculate the ratio of (potential) revenue (income) and operational costs (expenditure).

Equation 16

$$I / E\,(-) = \frac{\textit{Sum of all Income } (\$/year)}{\textit{Sum of all Expenditure } (\$/year)}$$

Potential revenue is estimated based on the yearly revenue from sales of the end-product(s) and sometimes also includes revenue for accepting the waste at the facility (tipping fees or gate fees). Expenditures are estimated based on the yearly operational (running) costs. These include costs for land rent, labour, water, fuel, maintenance and depreciation on equipment and infrastructure. The depreciation costs are based on the investments costs and the lifetime of the installations (see details in Table 61).

It is important that both income, as well as expenditure, have the same currency and time unit, e.g. per year. The I/E should be understood as follows:

- I/E>1 : The activity is economically profitable. The higher the number, the more profit that is generated
- I/E = 1 : The revenue is equal to the costs. The activity will not generate any income or costs
- I/E<1 : The activity is economically not viable

Table 61 explains how to calculate income and expenditures, as well as what kind of data you need to do this:

Table 61: Data needed to predict the economic feasibility of the technologies

Data	Description
Investment costs	Information needed: • Land acquisition costs • Construction costs: roofing, structures, etc. • Purchase costs of equipment: shredders, sieves, etc. Information on equipment needed to be considered can be found in the section "Equipment and spare parts needs" in Step 5, and the section "High technical reliability". Do not forget to consider pre/post-treatment equipment when necessary (heating/drying system, etc.). • Purchase costs of materials: shovels, boots, etc. Means to get it: • Interview companies who build the technologies and ask about approximate investment costs. It is recommended to check for installations in the following order: neighbourhood > city > municipality > province > department > country. The closer the technology was built, the more similar the investment costs will be. • Search on the internet
Operational costs (per year)	The operational costs include five individual costs: 1. Labour costs per year (L) - Information needed: • N: Number of workers per ton of suitable waste treated per day (from Table 47). Check if there are different salaries depending on worker type (role or position) • $C_{salaries}$: yearly salary for each worker type - For each type of worker (i), multiply the number of workers (N) times the yearly salary of this type of worker and then sum up the result from all types of workers (M): *Equation 17* $L = \sum_{i}^{M} N_i \cdot C_{salaries,type_i}$ 2. Water costs per year (W): - Information needed: • $M_{biowaste}$: Amount of suitable biowaste per year (Table 16) • M_{water}: Amount of water (m^3) consumed for ton of waste (from Table 49) • C_{water} : costs per unit of water (m^3). - Formula: *Equation 18* $W = M_{biowaste} \cdot M_{water} \cdot C_{water}$

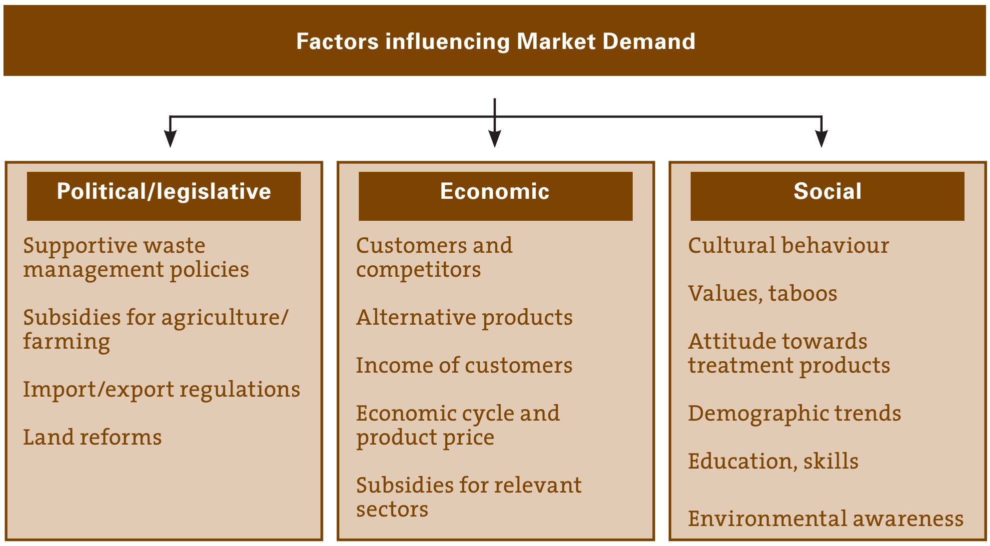
Data	Description
Operational costs (per year)	3. Energy costs per year (E): - Information needed: • $M_{biowaste}$: Amount of suitable biowaste per year (Table 16) • M_{Energy}: Amount of energy required per ton of waste (from Table 50). • C_{Energy}: costs per unit of energy. - Formula: *Equation 19* $E= M_{biowaste} \cdot M_{Energy} \cdot C_{Energy}$ 4. Maintenance costs per year (M) - Means to get it: interviews, statistics, etc. - When no data are available, can be estimated at 20% of the total of other operational costs *Equation 20* $M= \frac{(L+W+E+D) \cdot 20}{100}$ 5. Depreciation costs per year (D): - Amortization costs are also included here. - Information needed: • Investment costs. • Lifespan of technology (Table 16). - Formula: *Equation 21* $D= \frac{\textit{Investment Costs (currency)}}{\text{Lifespan (years)}}$ Equation 22 shows the final formula to compute the total operation costs per year: *Equation 22* $\textit{Operational costs} = L + W + E + M + D$

Data	Description
Market price of the product (ε)	Sources: • First, check if the possible products per technology stated in Table 16 already have a market value in your case study. • If not, the price of alternative products should be considered. This could be adjusted based on expert advice (increased or reduced).
Revenue from end product	1.Revenue for composting, in-vessel composting, vermicomposting, BSF processing and slow pyrolysis (Equation 23) - Information needed: • $M_{biowaste}$: Amount of suitable biowaste per year within the system boundaries. Calculated as explained in section "High treatment capacity", in Step 5. • δ: Mass reduction of the biowaste during treatment in percentage (from Table 16) • α: Marketability ratio (see the next section on Market assessment for more details) • ε: Market price per unit of end-product - Formula: *Equation 23* $Revenues = M_{bio\text{-}waste} \cdot (1 - \delta) \cdot \alpha \cdot \varepsilon$ Revenue for Anaerobic digestion (Equation 24): - Information needed: • $M_{biowaste}$: Amount of suitable biowaste per year (from section "High treatment capacity", in section 5) • β: Amount of biogas generated per unit of biowaste (from Table 11) • θ: Amount of digestate generated per unit of biowaste (from Annex 6) • α_β: Percentage of the generated biogas that can be commercialized (see the next section Market assessment for more details) • α_θ: Percentage of the generated digestate that can be commercialized (see the next section Market assessment for more details) • ε_β: Market price per unit of biogas. • ε_θ: Market price per unit of digestate. - Formula: *Equation 24* $Revenues = M_{biowaste} \cdot [\beta \cdot \alpha_\beta \cdot \varepsilon_\beta + \theta \cdot \alpha_\theta \cdot \varepsilon_\theta]$

In the case of commercial scale plants, being economically sustainable is an important criterion. Unless there are subsidy schemes in place, most of this profit derives from the revenue obtained by selling the end products generated from the treatment. The more end product sold, the more revenue will be obtained. The question to be asked is: how much of the generated product can actually be sold? This crucial aspect is measured by the marketability ratio **(α)**.

In order to evaluate the marketability ratio **(α)** of a product, political/legislative, economic and social factors need to be considered (Figure 30). As these aspects may change over time, it is important to continuously monitor changes in these areas.

Figure 30: Factors influencing market demand (adapted from Zurbrügg (2008)



Political and legislative factors

The marketability of a product can be restricted or enhanced by legislation. In many European countries, compost from non-source-separated biowaste cannot be applied in agriculture. Therefore, it is very important to have a look at the current legislation in your country/region to make sure you will not be facing similar restrictions for one or some of the possible end-products (compost, vermicompost, gas, animal feed, or char).

Legislation and regulations related to the use and commercialisation of waste-derived products may vary from country to country. Check your specific context by asking the following questions:

- Can the waste-derived products be commercialised from a legal perspective?
- Are local or national incentives provided to support the commercialisation of these products (e.g. subsidies)?
- Is the access to and use of biowaste (or certain biowaste types) hindered by legal restrictions?

In order to get this information, interviewing experts or consulting such legislative documents as the ones shown below could be useful:

- Environmental laws - may include legislation supporting or limiting waste recycling and reuse
- Solid waste management rules and regulations - may support waste recycling and reuse
- Agricultural laws - may regulate the use of soil amendment or organic fertiliser from waste source
- Trade laws and regulations – you may have to register your product if you want to commercialise it

This information can also be obtained from lawyers, NGOs, agricultural or business associations, agricultural research institutes, university departments or even the municipal authorities.

If legislation/regulation prohibits the use of a specific biowaste-derived product, then the marketability ratio **(α)** (Equation 23) is automatically 0, as well as the potential revenue attached to it. If you consider that the commercialisation will be limited by some legislative concerns, then a percentage for **α** between 0% and 100% should be estimated.

Economic factors

The marketability of a product (α) is highly influenced by potential and existing customers and competitors, as well as the price of the product **(ε)**, and the income of the customers.

A customer is someone who wants or needs your product and is able or is willing to pay for it (Zurbrügg, 2008). One can differentiate between different customer groups. For compost, Table 62 distinguishes between several customer groups based on the geographic location, volume, quality of end product and frequency of demand.

Table 62: Example of customer groups for compost

Customer group	Geographical location	Volume	Quality of end product	Frequency of demand
Farmers	Rural area	High	Medium-High	Seasonal/ annual demand
Cash crop farmers	Peri-urban	High	Very high	Seasonal – twice a year
Nurseries	Urban and peri-urban	Medium	High	Frequent demand
Real estate developers	Urban	High	Low	Irregular but high demand at one time
Middle/high income house-holds	Urban	Low	Very high	Not very seasonal but peaks in spring

Step 5

Table 63: Summary of potential customer and alternative product for price estimation per product type

Type	Compost/ Vermicompost	Larvae	Gas	Char	Oil
Potential customers	Farmers Nurseries Gardening Households Hotels …	Chicken farming Fish farming Pig farming …	Households Municipality Small industries …	Households Bakeries Small industries Restaurants …	Households …
Alternative products for price estimation	Organic fertilizer Animal manure Slurry …	Chicken/fish meal …	Natural gas …	Coal Brown coal Charcoal …	Oil …

For each waste derived product, try to answer the following questions:

- What are the potential customer groups?
- Are they already consuming the waste-derived products (compost/vermicompost/ biogas/ char) ?
  - If yes, the following questions should be asked:
    1- Demand and offer: How much do they buy on a weekly/monthly/ yearly basis? Where do they buy it? Is there a large amount of suppliers? Do suppliers compete for selling this product?
    2- Price: What is the current price of the product (ε)? Is it considered expensive considering the average local income?
  - If no, try to answer the same questions as before for the product they are using which has the most similar properties to your waste derived product.

Hint:

Depending on the size of your area, it might be difficult to know exactly how many potential customers per product type there are. In this case, a rough estimation can be used based on the information provided by local stakeholders. In case you identified more than 10 potential customers per product type, you can randomly select 10 of them, analyse their answers and assume the same behaviour for the rest of the customers.

With the information about the demand, the supply and price, the marketability ratio (α) can be estimated. Let us now see the extreme examples:

- Assume that the waste derived product is already in high demand in the study area (i.e. exceeding the production capacity), there are no competitors selling the same or similar product, and the price is affordable considering the average local income. Then α reaches its maximum (100%).
- If, on the contrary, no one consumes the product due to high prices or there are more preferred products that local people purchase (competition), then α is automatically set to 0.

If you consider your situation to be between these two extremes, then a percentage for α between 0% and 100% should be estimated.

Social factors

Social acceptance or rejection concerning use and commercialisation of a waste-derived product greatly affects the product's marketability and varies greatly from country to country. Check your specific context by asking the following questions:

- Is it socially and culturally accepted to use a certain waste-derived product (e.g. compost, biogas or larvae)?
- Are there any beliefs that prohibit the use of waste-derived products (ancestral or religious)?
- Is a product rejected only when it originates from a certain feedstock (e.g. human faeces, animal excreta, etc.)
- Are customers concerned about using waste-derived products (e.g. fear of spreading diseases, etc.)?

In order to get this information, interviewing experts, community and/or religious leaders could be useful.

If it is socially and culturally not acceptable to use a specific biowaste-derived product, then the marketability ratio (α) is automatically 0. If you consider that the commercialisation will be limited by some social and cultural concerns, then a percentage for α between 0% and 100% should be estimated.

CSF – CASE STUDY

The economic feasibility of the technologies considered in this manual was assessed for the case of San Fernando City. For each technology considered, the investment costs, operational costs, market price of the end products, and the potential revenue were obtained. The main source of information were reports about other installations in the country; interviews with stakeholders who had managed an installation themselves were also conducted. In general, data were scarce.

Windrow Composting

Table 64 summarises the economic feasibility assessment of windrow composting in CSF. From personal communication with local compost sellers, we learnt that there was no demand for compost in CSF, which automatically implies a marketability value of 0% and, therefore, no revenue. Windrow composting has a IER of 0 and is, thus, not economically self-sustaining in this context.

Table 64: Economic feasibility assessment of Windrow composting in CSF

	Item	Unit	Value	Source
Investment costs	Construction	PHP	500'000	(GSO, 2014)
	Shredder	PHP	125'000	(CIDA et al., 2011)
	Sieve	PHP	100'000	Assumed 20% than shredder.
	Total	**PHP**	**725'000**	
O&M costs	Depreciation	PHP/month	2015	Assumed 30 years lifespan
	Labour	PHP/month	16'500	3 workers (Table 48) 22 working days per month. Salary: 250 PHP/day (DLE, 2017)
	Fuel	PHP/month	18'000	Assumed equal to In-vessel composting
	Water	PHP/month	3'370	2160 L/day (Table 56) 52 PHP/m^3 (MSFWD, 2012)
	Total	**PHP/month**	**39'885**	
Revenue	Biowaste	ton/month	45	Calculated from Table 46
	Mass reduction	%	37.5	Table 16
	Mass of compost	ton/month	28.1	Calculated
	Market price	PHP/kg	7	Field observation: 300-400 PHP per 50 kg sack
	Marketability	%	0	(Expert, 2014)
	Revenue	**PHP/month**	**0**	

PHP: Philippine Peso, local currency

$$IER_{Windrow\ C.} = \frac{0}{39'885} = 0$$

In-vessel composting

Table 65 summarises the economic feasibility assessment of in-vessel composting in CSF. With windrow composting, the marketability value is 0% and, therefore, this treatment technology generates no revenue. In-vessel composting has an IER of 0 and is, thus, not economically self-sustaining in this context.

Table 65: Economic feasibility assessment of In-vessel composting in CSF

	Item	Unit	Value	Source
Investment costs	Bio-reactor	PHP	557'000	(DENR et al., 2011)
	Construction	PHP	500'000	(GSO, 2014)
	Shredder	PHP	125'000	(CIDA et al., 2011)
	Sieve	PHP	100'000	Assumed 20% than shredder.
	Total	**PHP**	**1'282'000**	
O&M costs	Depreciation	PHP/month	5'340	Assumed 20 years lifespan
	Labour	PHP/month	11'000	2 workers (Table 48) 22 working days per month. Salary: 250 PHP/day (DLE, 2017)
	Maintenance	PHP/month	15'000	(CIDA et al., 2011)
	Fuel	PHP/month	18'000	(CIDA et al., 2011)
	Water	PHP/month	3'200	2050 L/day (Table 56) 52 PHP/m³ (MSFWD, 2012)
	Total	**PHP/month**	**52'540**	
Revenue	Bio-waste	ton/month	45	Calculated from Table 46
	Mass reduction	%	35	Table 16
	Mass of compost	ton/month	29.3	Calculated
	Market price	PHP/kg	7	Field observation: 300-400 PHP per 50 kg sack
	Marketability	%	0	(Expert, 2014)
	Revenue	**PHP/month**	**0**	

$$IER_{In\text{-}veseel\ C.} = \frac{0}{50'760} = 0$$

Step 5

Vermicomposting

Table 66 summarises the economic feasibility assessment of vermicomposting in CSF. Although there is no demand for vermicompost in CSF, this technology generates a second product: worms. From personal communication with local compost sellers, we learnt that worms are in demand for home composting and that all could be sold (marketability of 100%). However, the revenue obtained from selling the worms is smaller than the operation and maintenance costs and, therefore, we get a IER<1 (IER = 0.24). This automatically implies that this treatment technology generates no revenue and is, thus, economically not self-sustaining in this context.

Table 66: Economic feasibility assessment of Vermicomposting in CSF

	Item	Unit	Value	Source
Investment costs	Construction	PHP	72'600	Biowaste: 930 kg/day Surface needed: 300 – 580 m2 per ton/day (Table 16) 20 m² cost 3'300 PHP (CIDA et al., 2011)
	Shredder	PHP	125'000	(CIDA et al., 2011)
	Sieve	PHP	100'000	Assumed 20% than shredder.
	Total	**PHP**	**297'600**	
O&M costs	Depreciation	PHP/month	1'240	Assumed 20 years lifespan
	Labour	PHP/month	11'000	2 workers (Table 48) 22 working days per month. Salary: 250 PHP/day (DLE, 2017)
	Maintenance	PHP/month	15'000	(CIDA et al., 2011)
	Fuel	PHP/month	18'000	Based on In-vessel composting (CIDA et al., 2011)
	Water	PHP/month	1'950	1'250 L/day (Table 56) 52 PHP/m3 (MSFWD, 2012)
	Total	**PHP/month**	**47'190**	
Revenue	Biowaste	ton/month	27.9	Calculated from Table 46
	Mass reduction	%	60	Table 16
	Mass of compost	ton/month	11.2	Calculated
	Market price	PHP/kg	8	Green Kit, p 144.
	Marketability compost	%	0%	(Expert, 2014)
	Revenue	**PHP/month**	**0**	
	Mass worms	kg/month	23	Calculated (see next page)
	Market price	PHP/kg	500.0	(CIDA et al., 2011)
	Marketability worms	%	1	(Expert, 2014)
	Revenue worms	**PHP/month**	**11'500**	
	Total revenue	**PHP/month**	**11'500**	

The mass of worms on vermicomposting was calculated using the following data from Munroe (2007).

- *580 m^2/ton per day of surface are required.*
- *Stocking density of 2.5 - 5 kg worms/m2 (3.75 kg/m^2)*
- *Worm biomass doubles every 90 days. 1/3 increase of original biomass per month.*
- *Biowaste pile of 50kg/m^2 in vermi-beds (assumed)*

Calculations:

- *Surface required per day:* $\frac{930\ Kg / day}{50\ kg / m^2} = 18.6\ m^2/day$
- *Retention time of waste:* $\frac{580\ m^2}{18.6\ m^2 / day} = 31$ *days (4.45 weeks) which is enough for vermicomposting treatment (Munroe, 2007).*
- *Original worm biomass required is: 18.6* 3.75 = 69.75 kg.*
- *Worm biomass production: in a month this will increase 1/3 of its weight, which amounts to: 23.22 kg. This is what can be sold.*

$$IER_{Vermic.} = \frac{11'500}{50'760} = 0.24$$

Step 5

Anaerobic digestion

Table 67 summarises the economic feasibility assessment of anaerobic digestion in CSF. This treatment technology generates two output products: biogas and digestate. In the case of CSF, there was no demand for the digestate and, therefore, it generates no revenue. The biogas, however, showed a marketability of 100%. The market price of it is based on that of natural gas. The revenue generated is larger than the O&M costs estimated and, therefore, AD is presumably a profit-making treatment technology in CSF. Due to the fact that the water costs represent a big share of the O&M costs, a new IER was calculated considering that wastewater is used to remove the cost for water.

Table 67: Economic feasibility assessment of Anaerobic Digestion in CSF

	Item	Unit	Value	Source
Investment costs	Construction	PHP	557'000	(DENR et al., 2011)
	Shredder	PHP	125'000	(CIDA et al., 2011)
	Total	**PHP**	**682'000**	
O&M costs	Depreciation	PHP/month	2'270	Assumed25 years lifespan
	Labour	PHP/month	11'000	2 workers (Table 48) 22 working days per month. Salary: 250 PHP/day (DLE, 2017)
	Water	PHP/month	5'460	3'500 L/day (Table 56) 52 PHP/m³ (MSFWD, 2012)
	Total	**PHP/month**	**18'730**	
Revenue	Biowaste	ton/month	27.9	Calculated from Table 46
	Digestate volume	m³/day	4'236	Calculated (Annex 6)
	Market price digestate	PHP/m³	0	(Expert, 2014)
	Marketability	%	0	(Expert, 2014)
	Revenue digestate	**PHP/month**	**0**	
	Biogas	m³/month	3'515	Calculated (check Annex 6)
	Market price biogas	PHP/m³	7	Estimated based on natural gas price
	Marketability	%	100	(CENRO, 2014)
	Revenue worms	**PHP/month**	**24'610**	
	Total revenue	**PHP/month**	**24'610**	

$$IER_{AD\ (buy\ water)} = \frac{24'610}{18'730} = 1.3$$

$$IER_{AD\ (waste\ water)} = \frac{24'610}{13'270} = 1.8$$

Black Soldier Fly

Table 68 summarises the economic feasibility assessment of Black Soldier Fly processing in CSF. This treatment technology generates two output products: larvae and residue. In the case of CSF, there was no demand for the residue; therefore, it generates no revenue. The larvae, however, showed a marketability of 100% since they could be used as a cheaper alternative than chicken feed. The market price of the larvae is based on that of vermicomposting worms. The revenue generated is bigger than the O&M costs estimated; therefore, Black Soldier Fly processing is presumably a profit-making treatment technology in CSF.

Table 68: Economic feasibility assessment of Black Soldier Fly in CSF

	Item	Unit	Value	Source
Investment costs	Equipment & materials	PHP	2’500’000	(Dortmans, 2017)
	Roofing	PHP	500,000	From interview
	Total	**PHP**	**3’000’000**	
O&M costs	Depreciation	PHP/month	12’500	Assuming 20 years lifetime
	Labour	PHP/month	16’500	3 workers (Table 48) 22 working days per month. Salary: 250 PHP/day (DLE, 2017)
	Electricity & Fuel	PHP/month	3’500	(Dortmans, 2017)
	Water	PHP/month	1’155	740 L/day (Table 56) 52 PHP/m³ (MSFWD, 2012)
	Total	**PHP/month**	**33’655**	
Revenue	Biowaste	ton/month	0.93	Calculated from Table 46
	Mass reduction	%	67.5	Table 16
	Mass of residue	ton/month	0.30	Calculated
	Market price residue	PHP/kg	0	(Expert, 2014)
	Marketability residue	%	0%	(Expert, 2014)
	Revenue residue	**PHP/month**	**0**	
	Mass larvae	kg/month	232.5	Biowaste to larvae biomass conversion rate 25% (Dortmans et al., 2017)
	Market price larvae	PHP/kg	250	Assumed to be 50% of vermiworms
	Marketability larvae	%	100%	(CENRO, 2014)
	Revenue worms	**PHP/month**	**58’125**	
	Total revenue	**PHP/month**	**58’125**	

$$IER_{BSF} = \frac{58'125}{33'655} = 1.7$$

Step 5

Slow Pyrolysis

Table 69 summarises the economic feasibility assessment of slow pyrolysis in CSF. Charcoal is a common fuel used in CSF and, therefore, local stakeholders stated that if sold cheaper than charcoal, it would be well received and purchased. When calculating the potential revenue, we can see that they exceed the operation and maintenance costs three fold. This automatically implies that slow pyrolysis is presumably a profit-making treatment technology in this context.

Table 69: Economic feasibility assessment of Slow Pyrolysis in CSF

	Item	Unit	Value	Source
Investment costs	Equipment	PHP	616'060	(GSO, 2014)
	Total	**PHP**	**616'060**	
O&M costs	Depreciation	PHP/month	5'140	Assuming 10 years lifespan
	Labour	PHP/month	22'000	4 workers (Table 48) 22 working days per month. Salary: 250 PHP/day (DLE, 2017)
	Water	PHP/month	190	120 L/day (Table 56) 52 PHP/m³ (MSFWD, 2012)
	Other expenses	PHP/month	17'700	(GSO, 2014)
	Total	**PHP/month**	**45'030**	
Revenue	Biowaste	ton/month	46.6	Calculated from Table 46
	Mass reduction	%	65	Table 16
	Mass of char	ton/month	16.3	Calculated
	Market price	PHP/kg	10	Lower end of charcoal price in CSF: 10 PHP/Kg
	Marketability	%	50%	(Expert, 2014)
	Total revenue	**PHP/month**	**81'550**	

$$IER_{Slow\ pyrolysis} = \frac{81'550}{45'030} = 1.8$$

Summary

Table 70 shows the summary of all economic assessments.

Table 70: Summary of economic assessments for all treatment technologies

	Windrow Composting	In-vessel composting	Vermi-composting	AD	BSF	Slow Pyrol.
O&M costs	39'885	52'540	47'190	18'730	33'655	45'030
Revenue	0	0	11'500	24'610	58'125	81'550
IER	0	0	0.24	1.3	1.7	1.8

STEP 6:
What is the relative importance between objectives? Workshop to elicit the preferences

If you are ready to work on this sixth step, it means that you have already accomplished the list below:

- a well delimited study area
- amounts of biowaste generated and separated into different types based on their characteristics
- a list of stakeholders who you consider relevant
- a selection of biowaste treatment technologies
- a validated objective hierarchy with corresponding attributes
- an estimation of the performances of every technology for every objective

Now that you have estimated the performance of every technology for every objective and, therefore, accomplished Step 5, let us focus on the set of objectives you will use in order to compare the different biowaste treatment technologies. This is the content of this chapter.

Before we focus on the set of objectives, there are a few questions we should answer:

- Are all objectives equally important?
- Which objectives are more important than others?
- How much more important is one objective than the other?

Determining the differences in the objectives' relative importance is what we call *Preference elicitation*. Preference elicitation basically implies asking the stakeholders to score the objectives according to their perceived importance. These scores show how important each objective is for a specific stakeholder. Different stakeholders will, however, most likely assign different scores to the objectives.

Example: *preferences according to different stakeholders*

An environmental manager will probably score the objective "high environmental protection" higher than other stakeholders.

A business-oriented stakeholder will most likely score "high economic feasibility" higher than other stakeholders.

Taking into consideration these different opinions is very beneficial for the project because:

- it involves all stakeholders in the decision making
- it helps in understanding what different stakeholder groups value more and less
- it facilitates a dialogue and future tradeoffs between the stakeholders

In this chapter, we will explain how to elicit the preferences of the stakeholders identified in Step 2, Stakeholder Analysis. The preference elicitation is carried out by using the "Swing" and "Reverse Swing" methods. The preference elicitation is normally conducted in an interview format, face-to-face, with the respondent. It is very important that the person asking the questions be familiar with the methods and understands the rationale behind them. The interviewer will never talk to the relevant stakeholders about the different biowaste treatment technologies to be considered. The interviewees should never see or hear the names of the technologies considered in the selection process. This might seem weird at the beginning. However, it is a very important condition to avoid unconscious biases, preferences or rejections towards some technologies. The interviewees will only be asked about objectives, and which objectives they consider more important than others.

The next sub-chapters will cover the following points:

- Preparing and printing the material
- Introducing the method to the interviewee
- Presenting the "Best-Worst case scenarios"
- Running the Swing Method
- Running the Reverse-Swing Method
- Discussion with the interviewee

The final weight values need to be calculated afterwards. This will be explained in Step 7.

PREPARING AND PRINTING THE MATERIAL

There are three documents/printouts that need to be prepared to run the preference elicitation interview. Table 71 shows the documents, and how many of which need to be printed:

Table 71: Documents required for preference elicitation interview

Document	Purpose	Number
Best – Worst scenarios	Descriptive	One is enough (always good to have a copy)
Swing method	Questionnaire to fill in	As many as interviewees there are
Reverse swing method	Questionnaire to fill in	As many as interviewees there are

In the following, we will describe how to prepare the above documents.

BEST-WORST CASE SCENARIOS

The very first step in preparing for the preference elicitation interview is to prepare the "Best-Worst case scenarios". These are used as a baseline for the Swing and Reverse Swing approaches. In other words, these scenarios are based on the Table 26 you completed in Step 5.

In order to create the "Best-Worst case scenarios", identify the best and worst score per attribute as explained below.

Table 72: Best-Worst case scenario description

Best-case scenario	Worst-case scenario
Pick the most promising performance in every line of the table and create a hypothetical technology that combines all those promising performances.	Pick the least promising performance in every line of the table and create a hypothetical technology that combines all those bad performances.

Table 73 shows the analysis of the "Best-Worst case scenarios" based on the data from Table 26. These are the scores obtained by the technologies for the case of San Fernando City. The best and worst outcomes per objective (and sub-objective) are marked in green and red, respectively.

Hint:

We recommend extending the extreme values a bit further in order to allow any further alternatives that could score better or worse than the ones considered to be incorporated. Table 74 provides, again, the "Best-Worst case scenarios" with extended values. We strongly recommend preparing a table similar to Table 74 and to bring it to the interviews.

Table 73: Best-Worst scenarios based on the data from CSF

Objectives	Sub-objectives	Attributes	Composting Windrow	In-vessel composting	Vermicomposting	AD	BSF	Slow Pyrolysis	Best case scenario	Worst case scenario
High technical reliability	-	Days per year of downtime (day/year)	23	53	27	0	60	0	0	60
High Social impact	Few working hazards	Percent of maximum level of hazard the workers are exposed to per technology (%)	25.7	15.8	17.8	13.8	15.1	47.4	13.8	47.4
	Low nuisance level for community	Percent of maximum level of nuisance the community suffers from per technology (%)	75	67.9	64.3	35.7	71.4	75	35.7	75
	High job creation	N° of workers per ton of waste treated per working day (worker/ton per day)	2 - 4	2 - 3	1	1	3	3 - 5	3 - 5	1
High environmental protection	Low emission generation	Emission of CO_2 equiv. per day (kg CO_2 eq./day)	163	81.4	3.5	39	2.1	365.7	2.1	365.7
	Low risk of eutrophication	Leachate-risk level (1-5)	2	1	3	1	2	1	1	3
High contribution to waste management	High treatment capacity	Percentage of the collected biowaste that can be treated by the technology (%)	60.5	60.5	37.5	37.5	37.5	62.5	62.5	37.5
	Low residue generation	Percentage of residue over original wet waste (%)	0	0	0	100	32.5	0	0	100
High economic feasibility	-	Income-expenditure ratio (-)	0	0	0.24	1.3	1.7	1.8	1.8	0

Table 74: Best-Worst Case scenarios for the case of CSF with extended values

	High technical reliability	**High social impact**	**High environmental protection**	**High contribution to waste management**	**High economic feasibility**
Best case scenario ☺	*0 day/year downtime*	*10% of hazards 30% of nuisance 5 workers/ton per day*	*0 kg CO_2 equivalent 1 leachate risk*	*70% of collected waste can be treated 0% wet waste weight as residue*	*2 Income expenditure ratio*
	High technical reliability	**High social impact**	**High environmental protection**	**High contribution to waste management**	**High economic feasibility**
Worst case scenario ☹	*75 days/year downtime*	*50% of hazards 80% of nuisance 1 workers/ton per day*	*400 kg CO_2 equivalent 5 leachate risk*	*30% of collected waste can be treated 100% wet waste weight as residue*	*0 Income expenditure ratio*

SWING METHOD QUESTIONNAIRE

The Swing method is a scoring system used to identify how important the objectives are relative to one another. The questionnaire required for the Swing method can easily be prepared once the "Best-Worst case scenarios" are ready (Table 74).

The questionnaire will consist of many hypothetical technology descriptions, called scenarios.

Baseline:	The worst case scenario is taken as a baseline
Scenarios:	Each new scenario is created by changing the performances of only one of the attributes to the best state. Since we are dealing with five main objectives, that means that you will end up with five scenarios/ technology descriptions.

The sub-objectives referring to the same objective also need to be compared against each other. Remember, only three out of five main objectives are composed of sub-objectives: "high social impact", "high contribution to solid waste management" and "high environmental protection". The sub-objectives under the same objective are compared by preparing a worst case scenario where they have the worst possible scores (worst case scenario). Then, the scenarios are created by changing the performance of one sub-objective to the best state one at a time.

Please have a look now at Annex 7. There, you will find a template of the Swing method prepared with the values of the CSF case study. First, the baseline (worst case scenario) for the main objectives is shown followed by the five artificial scenarios. Then, the worst-case scenario and artificial scenarios for each sub-objective are presented.

REVERSE SWING METHOD QUESTIONNAIRE

The Reverse Swing Method serves as a consistency check to assess the strength of the opinion given by the interviewed stakeholder during the Swing Method. The Reverse Swing questionnaire is actually the opposite of the Swing questionnaire.

Baseline:	The baseline situation is the "Best-case scenario".
Scenarios:	Each additional scenario is generated by shifting one of the attributes from the best case to the worst case scenario.

Please check now the "Reverse Swing " in Annex 7 and compare it to the Swing-method questionnaire.

INTRODUCTION OF THE METHOD

Once all the material is prepared, you are ready to conduct the interviews! After arranging meetings with the specific stakeholders, you can proceed as explained below.

In order to carry out the process of preference elicitation in a successful way, the following information should be given to the interviewee:

- Explain who the interviewer is
- What the purpose is of the research
(i.e. assist in the selection of a biowaste treatment technology)
- Which is the institution behind it, if any
- How the results are going to be treated (anonymous or not anonymous)
- Why the interviewee was chosen for this specific exercise (as a stakeholder group representative, involvement level, etc.)

Then, the duration and the structure of the interview should be explained. The interview normally takes **one and a half to two** hours and consists of four different parts.

• Presenting the "Best-Worst case scenarios"
• Running the Swing Method
• Running the Reverse-Swing Method
• Discussion with the interviewee

PRESENT BEST-WORST CASE SCENARIOS

The explanatory table, called "Best-Worst case scenarios" (similar to the one shown in Table 74) is the **first thing that you will show to the interviewee.** Guide the interviewee through both scenarios:

Important:	It is very important that the interviewee understands **what the best possible option is and what the worst** that exists is in the specific case study.
Tips:	The interviewer should **clearly explain every performance score and also explain the units** used for every attribute if they are not clear.

The following paragraph provides an example of an explanation given by the interviewer to the interviewee on how to describe these two scenarios to the interviewee. Notice the level of detail when explaining each attribute and its units.

Example: *interviewer talking to interviewee*

"If you observe the performance of the worst scenario for technical reliability, you will notice that the worst possible technology in CSF would have a downtime time of 75 days per year.

As for social impact, you see that the worst alternative would have half of the maximum percentage of potential hazards for workers (50%). The potential hazards are measured on a percentage scale that goes from 0, which means no risks for the workers, to 100, which means there is a maximum level of potential hazards. Examples of hazards are contact with chemicals, sharp objects or hot surfaces, the inhalation of gases and aerosols, noise, UV radiation, etc. This means that the worst technology would cause 50% of the maximum level of hazards possible to the employees. The same technology would expose the community to 80% of the maximum level of nuisance that can be achieved. Examples of nuisances that may affect a community are pest proliferation, the inhalation of aerosols, noise and odours. This technology would also generate employment for one person.

When it comes to environmental protection, this technology would emit 366 kg of $C0_2$ equivalents and would represent the maximum level of risk for eutrophication, meaning that it can contaminate water bodies in the vicinity of the installation.

The technology would only be able to treat 30% of the biowaste collected, and the same amount of waste would be converted into residue, which would later require disposal.

In the end, it would never make any profit.

The best performing technology, on the other hand, would score very differently. It would have no downtime through the year. As for social impact, the workers would be exposed to 10% of the maximum hazard level, and it would cause 30% of the maximum nuisance level to the community and would generate employment for five people.

As for environmental protection, the best performing technology would emit two kg of CO_2 equivalents and would represent the lowest risk of eutrophication: there would be no leachate generated.

The technology would be able to treat 70% of the collected biowaste and would not generate any residue for further disposal.

Finally, with this technology, the revenue would represent twice the expenses, which means it would generate a profit.

When explaining the scenarios to the interviewee, we recommended doing it while having the sheet of the "Best-Worst scenario" in front of you. Point at each figure as it is mentioned.

Some performances might be difficult to grasp for somebody without any environmental or economic background. For instance, how bad is it to emit 366 kg CO_2 equivalents into the atmosphere? In this case, we recommend finding similar examples that could be understood:

"When it comes to environmental protection, this technology would emit 366 kg of CO_2 equivalents, which is approximately what four heavy trucks emit when they drive 100 km each. Furthermore, the technology would represent the maximum level of risk for eutrophication, which would represent a threat to the water bodies around the installation. Eutrophication is a chain reaction that leads to the degradation of the water bodies. Consequently, the water bodies lose their capacity to sustain life (fish, crustaceans, etc.)".

RUN THE SWING METHOD

After presenting the "Best-Worst case scenarios", the Swing method can be carried out. This section explains how to run this workshop.

It is important to keep in mind that, as the interviewer, you can have great influence on the results depending on how you present the different values or ask the questions. It is necessary to be as explicit and neutral as possible. Do not hesitate to rephrase the question as many times as necessary to avoid a biased answer.

The step-by-step approach used to carry out the *Swing Method* is as follows:

a) Give the Swing Method questionnaire to the interviewee.

- The first thing that the interviewee will see in the Swing method is the same **Worst-case scenario** presented in the previous step.
- This scenario is now the reference state to which the interviewee will have to compare other alternatives. This Worst-case will be scored 0 points.

b) Ask the interviewee to imagine the alternatives you will describe to him/her next, in which only one of the attributes is moved to the best state.

From this set of alternatives the interviewee will be asked to choose the one that he/she would prefer the most. That alternative will score 100.

Hint:

Make sure that the interviewee is aware of the tradeoffs that he/she is making when choosing an alternative. This can be done by summarising the decision of the interviewee out loud, similar to the example given in the previous page or by rephrasing the choice the interviewee just made and making him/her aware of the trade-offs.

Once the **most preferred alternative** is chosen, the interviewee will be asked for his second best alternative, followed by the third and so on. Each of these alternatives will have to be scored with a lower score than the previous one (all between 0 and 100).

The relative distance in his/her preference among each alternative should be stated. The interviewer should help the interviewee regarding these distances.

Examples of questions that can be asked during the interview:

- How much less do you prefer this scenario over the previous one?
- Is the distance of 20 points between these two scenarios representing your opinion?
- If you gave 100 points to your most preferred option, are you sure that your second most preferred option should score 90? (adapt the value accordingly)

Hint:

Sometimes it might happen that one stakeholder gives the same points to two or more scenarios. In theory, this is not advisable. The interviewer should discuss with him/her in order to identify which one is the relative preference.

c) Once the objectives are scored, the same will be done for the sub-objectives. Only those sub-objectives that are under the same objective can be scored against each other. That is to say, the sub-objectives of "High social impact" will be compared to other sub-objectives under "High social impact" and not to sub-objectives from other objectives.

RUN THE REVERSE SWING METHOD

After completing the Swing method, the Reverse Swing method needs to be carried out. This section presents the definition and basic principles, followed by the step-by-step approach used in practise.

Once again, the influence of how the interview is conducted is of great importance. The same advice given for the Swing Method is applied here. The steps are:

a) Give the Reverse Swing method questionnaire to the interviewee. In this questionnaire, the Best-case scenario is presented first. This will be the reference state to which the interviewee will have to compare other alternatives. This Best-case (all attributes at best level) will be scored 100 points.

b) Ask the interviewee to imagine the alternatives you will describe to him/her in which only one of the attributes is changed to the worst state. From this set of alternatives, the interviewee will be asked to choose the one that he/she dislikes most. That alternative will score 0.

Note: all but one of the attributes are at the best level, so it could happen that an interviewee disagrees and says *"but I do not agree. This scenario cannot score 0, it only scores bad in one objective. It should deserve more than 0"*. It is important to clarify that the score 0 does not mean that the technology is worth nothing. The workshop is based on a scale that goes from 0 to 100, the best scenario gets the value 100 and the worst 0. We only care about the relative distances between the scores given, not the extreme values. This has to be discussed explicitly with the interviewees to avoid a biased evaluation.

c) Once the least preferred scenario is chosen, the interviewee will be asked for her/his second least preferred scenario, followed by the third and so on. The interviewee has then to specify scores, between 0 and 100, for the other scenarios with the attribute(s) of one objective at the worst level. The relative distance in his/her preference between each alternative should be stated. In order to get the specific values, the interviewer should help the interviewee to state those distances.

Examples of questions that can be asked during the interview:

- How much more do you prefer this scenario over the previous one?
- Is the distance of 20 points between these two scenarios representing your opinion?
- If you gave 0 points to your least preferred option, are you sure that your second least preferred option should score 10? (adapt the value accordingly)

OPEN FOR DISCUSSION

After running both interviews, you will ask the interviewee for a five-minute pause so that you can work on the answers given. Let us assume that you obtained the scores shown in Table 75 from an interviewee.

Table 75: Example of scores given in an interview – raw data

		Swing	Reverse Swing
Main objectives	High technical reliability	50	70
	High social impact	90	0
	High environmental protection	100	0
	High contribution to waste management	100	30
	High economic feasibility	70	50
High social impact	Few working hazards	100	0
	Low nuisance to community	50	50
	High job creation	75	30
Environmental protection	Low emission generation	100	0
	Low risk of eutrophication	70	30
High contribution to waste management	High treatment capacity	100	20
	Low residue generation	80	0

The following step-by-step approach can be carried out in order to check the relevance of the results:

1. Ranking of objectives (and sub-objectives)

What is the ranking of objectives? Based on the preference scores given to the scenarios, objectives can easily be ranked from the most important to the least important because each scenario directly represents one objective. For example, assume we are checking the preference scores given in the Swing interview, shown in Table 75. We see that the most preferred scenarios are those in which "high environmental protection" and "high contribution to waste management" had the best possible performances. They were both scored 100. From this, we infer that for the interviewee these two are the most important objectives, and that they are equally important (we will later check the consistency of this preference in the Reverse Swing). The next objective in the rank would be "high social impact" followed by "high economic feasibility" and finally "high technical reliability".

In order to get the ranking order from the scores given in the Reverse Swing method, an easy method is to apply Equation 25:

Equation 25

$$X = -\left(Value_{Reverse\ swing} - 100\right)$$

Table 76 shows the outcome of applying Equation 25 to the values given in Table 75. You can easily identify that the ranking of several objectives is not the same in both methods (numbers highlighted in red). In the Swing method, the objective "high environmental protection" scored higher than "high social impact", whereas in the Reverse Swing, it was the other way around. The same happens between "high treatment capacity" and "low residue generation". There is no consistency in those cases.

Table 76: Example of scores given in an interview – inconsistent ranking

		Swing	Ranking	Reverse Swing	Ranking
Main objectives	High technical reliability	50	4	30	4
	High social impact	90	2	100	1
	High environmental protection	100	1	70	2
	High contribution to waste management	70	3	50	3
	High economic feasibility	100	1	100	1
High social impact	Few working hazards	100	1	100	1
	Low nuisance to community	50	3	50	3
	High job creation	75	2	70	2
Environmental protection	Low emission generation	100	1	100	1
	Low risk of eutrophication	70	2	70	2
High contribution to waste management	High treatment capacity	100	1	80	2
	Low residue generation	80	2	100	1

Red numbers: different ranking in each method

The ranking given in both methods should, in theory, be the same. In theory, people should have ONE opinion. However, this is often not the case. In such cases, the interviewer should explain the inconsistency to the interviewee. Once the interviewee understands the different rankings given, he/she should reflect on which of the rankings is more proximate to his/her real preference. The text below provides an explanatory example of how to interact with the interviewee.

Example: *interviewer talking to interviewee - inconsistent ranking*

As you can see, in the first exercise (Swing) you said that the scenario which scored high for the objective "High contribution to solid waste management" and bad for all the other objectives was preferred over the alternative that scored high for "High social impact" and bad for all the other objectives. That means that you value "High contribution to solid waste management" more than "high social impact".

However, in the second exercise (Reverse Swing) your opinion changed and your least preferred scenario was that which scored bad for "high social impact" and good for all the other objectives, meaning that you mainly care about "high social impact".

You should refine this. Which of the scenarios do you prefer?

The interviewee should then refer back to the scenarios in the Swing method and the Reverse Swing method and ask the interviewer to think it through once more. If the real preference is something in between the results obtained for both methods, then the interviewee should specify the ranking order and the relative distances between the alternatives. Table 77 gives the final output from the interview (converting the new values obtained with the Reverse Swing again with Equation 25).

Table 77: Example of scores given in an interview – consistent ranking

		Swing	Ranking	Reverse Swing	Ranking
Main objectives	High technical reliability	50	4	30	4
	High social impact	90	2	90	2
	High environmental protection	100	1	100	1
	High contribution to waste management	70	3	50	3
	High economic feasibility	100	1	100	1
High social impact	Few working hazards	100	1	100	1
	Low nuisance to community	50	3	50	3
	High job creation	75	2	70	2
Environmental protection	Low emission generation	100	1	100	1
	Low risk of eutrophication	70	2	70	2
High contribution to waste management	High treatment capacity	100	1	100	1
	Low residue generation	80	2	80	2

2. Relative distances between objectives (and sub-objectives)

Now, the ranking is the same for both methods. However, notice that the points given in each method for the main objectives are not exactly the same, thus, the relative preferential distances between the objectives differ. As long as these distances are not diverging considerably from each other this is not a problem, since the average value of both points will be used later on.

If the distances are considerable, the interviewer should explain the inconsistency. Then the relative preferential distances should get closer by referring again to the scenarios shown in the Swing and Reverse Swing methods.

Examples of questions to ask during the interview:

- Is the distance of 20 points between these two scenarios representing your opinion as you stated in the first questionnaire (Swing) or is it rather 40 as you stated in the second questionnaire?
- How much more do you prefer this scenario over the previous one? 20 points? 40 points?

After coming up with a consistent ranking order and relative preferential distances, the interviewer can do a summary of the resulting preferences and conclude the interview.

STEP 7: What is the final score for each technology? Data analysis

At this point, if all the previous steps have been carried out satisfactorily, you should have a:

- Table of performances: the performances of all treatment technologies for every objective (similar to Table 26, but completed for all objectives).
- Preference elicitation: the scores given by every stakeholder interviewed to every objective and sub-objective.

This chapter will cover the following contents.

Step 7

PROCESSING WEIGHTS

Through the preference elicitation, you obtained an objective ranking with scores between 0 and 100. These scores need to be processed to obtain weights.

Weights are values that range from 0 to 1 and give an indication of the preferences of each stakeholder. To obtain weights, we normalise the scores obtained with the Swing method with Equation 26; Equation 27 is used to normalise the scores obtained with the Reverse Swing method.

Normalising the Swing method scores:

Equation 26

$$Weight_x = \frac{Score_x}{Score_x + Score_y + Score_z + ...}$$

Normalising the Reverse swing scores:

Equation 27

$$W_x = \frac{100 - Score_x}{(100 - Score_x) + (100 - Score_y) + (100 - Score_z) + ...}$$

Where:

- $Weight_x$: weight of objective or sub-objective x. This is the value we want to get.
- $Score_x$: score given to objective x during the Swing method (in Equation 26) or the Reverse Swing method (in Equation 27).
- In the denominator: we total all the scores given to the same level objectives or sub-objectives. The number of objectives to be considered are:

  - Five main objectives
  - Three sub-objectives for "High social impact",
  - Two sub-objectives for "High contribution to solid waste management"
  - Two sub-objectives for "High environmental protection"

As an example: Table 78 shows the points using the Swing method and Reverse Swing method. Next to the scores given in the questionnaires, the derived weights are also shown.

Table 78: Scores and correspondent weights of the fundamental objectives

		Swing method		Reverse Swing method		Average weights
		Points	Weight[1]	Points	Weight[2]	
Main objectives	High technical reliability	50	0.122	70	0.081	0.102
	High social impact	90	0.220	10	0.243	0.231
	High environmental protection	100*	0.244	0	0.270	0.257
	High contribution to waste management	70	0.171	50	0.135	0.153
	High economic feasibility	100*	0.244	0	0.270	0.257
High social impact	Few working hazards	100	0.444	0	0.455	0.449
	Low nuisance to community	50	0.222	50	0.357	0.163
	High job creation	75	0.333	30	0.368	0.236
Environmental protection	Low emission generation	100	0.588	0	0.588	0.588
	Low risk of eutrophication	70	0.412	30	0.412	0.412
High contribution to waste management	High treatment capacity	100	0.556	0	0.556	0.556
	Low residue generation	80	0.444	20	0.444	0.444

[1]*Calculated using Equation 26;* [2]*Calculated using Equation 27*
**See that in this case two main objectives were scored 100.*

Calculation example from the Swing method scores and the sub-objective "Few working hazards":

$$W_{working\ safety} = \frac{Score_{w.safety}}{Score_{w.safety} + Score_{nuisance} + Score_{jobs}} = \frac{100}{100 + 50 + 75} = 0.444$$

The weights calculated from the Swing method scores and those from the Reverse Swing method scores may differ. In such cases, we use the average of both values (last column in Table 78).

As more than one stakeholder will be interviewed, the weights obtained will represent the opinion of different stakeholders. Very rarely will the weights of two different stakeholders match completely. With many stakeholders, it is not realistic to consider each preference separately. Three different approaches to aggregate the preferences are explained below.

- **Keep each Individual stakeholder separate (no aggregation):** if just a few stakeholders are involved in the decision process (i.e. fewer than five), their preferences (weights) can be taken into consideration individually.

- **Cluster by Stakeholder groups:** Different criteria can be used when clustering stakeholders. Possible clustering criteria can be: profession, interest level, power to influence, etc.

After each stakeholder has been assigned to one stakeholder group or cluster, the weights of each stakeholder in the same cluster are averaged for each objective (and sub-objective). It is important to be aware that we are losing some of the information, since the extreme opinions are lost through the averaging. This option is preferred if discussion among stakeholders is desired. Inviting all stakeholders and showing them the results of each stakeholder group will trigger discussion and, ideally, final consensus.

- **A total aggregated value among all stakeholders:** The last approach is to aggregate all the weights obtained from the different individual stakeholders by calculating one single average for each objective and sub-objective. This approach will not show the diversity between stakeholders or stakeholder groups.

NORMALISATION OF PERFORMANCES

When looking at your table of estimated performances (similar to Table 26), you will realise that a different unit is used to estimate the performances of each objective for every technology (e.g. days/year, % of maximum hazard level, workers employed, level of risk of eutrophication, income-expenditure ratio, etc.). The performances need to be normalised into a unit-less scale that goes from 0 to 1 in order to calculate the aggregated performance of every technology for all objectives. The value 0 indicates the worst value and 1 the best value. The step-by-step approach is the following:

1) Check the performances of the technologies under consideration
Consider once more the best and worst values as explained in Table 73. In theory, we should assign the value 0 to the worst performance and 1 to the best. However, similar to what we did before (Table 74), we advise you to extend the values for the best and worst performances a bit. This is to ensure that if a new treatment technology is considered in the future and it scores better or worse than current ones, it will not fall out of the scale from 0 to 1.

2) Checking the "direction of changes" of the objectives
If you remember, we said that every objective needs to be phrased with a direction: "low" or "high" in the case of the objective hierarchy of this manual:

- "low" or "few" : best value is the smallest » assigned to 1
- "high": best value is the highest » assigned to 1

3) Generating the normalised table
Now that we know the directions and we agreed on how much we will expand the best and the worst values, we are ready to generate the normalised table by using Equation 28.

Equation 28

$$N_X^Y = \frac{Performance_X^Y - Worst_X}{Best_X - Worst_X}$$

Where:

- N_X^Y: Normalised value of the performance of treatment technology Y for fundamental objective X.
- $Performance_X^Y$: The performance of treatment technology Y for fundamental objective X.
- $Worst_X$: the worst value obtained (extended value) for objective X.
- $Best_X$: the best value obtained (extended value) for objective X.

Once that is computed, the normalised table can be generated. Table 80 shows the normalized table for the case study of San Fernando.

Table 79: Obtained performances for CSF with extended best and worst values

	Main Objectives	Sub-objectives	Windrow Composting	In-vessel composting	Vermicomposting	AD	BSF	Slow Pyrolysis	Best value	Worst value
Performances	High technical reliability	Low downtime	23	53	27	0	60	0	0	75
	High Social impact	Few working hazards	25.7	15.8	17.8	13.8	15.1	47.4	10	50
		Low nuisance level for community	75	67.9	64.3	35.7	71.4	75	30	80
		High job creation	3.00	2.50	1	1	3	4	5	1
	High environmental protection	Low emission generation	163	81.4	3.5	39	2.1	365.7	0	400
		Low risk of eutrophication	2	1	3	1	2	1	1	5
	High contribution to waste management	High treatment capacity	60.5	60.5	37.5	37.5	37.5	62.5	70	30
		Low residue generation	0	0	0	100	32.5	0	0	100
	High economic feasibility	High income-expenditure ratio	0	0	0.24	1.3	1.7	1.8	2	0

Table 80: Normalized performances for CSF

	Main Objectives	Sub-objectives	Windrow Composting	In-vessel composting	Vermicomposting	AD	BSF	Slow Pyrolysis	Best value	Worst value
Performances	High technical reliability	Low downtime	0.69	0.29	0.64	1.00	0.20	1.00	1.00	0.20
	High Social impact	Few working hazards	0.61	0.86	0.81	0.91	0.87	0.07	0.91	0.07
		Low nuisance level for community	0.10	0.24	0.31	0.89	0.17	0.10	0.89	0.10
		High job creation	0.50	0.38	0.00	0.00	0.50	0.75	0.75	0.00
	High environmental protection	Low emission generation	0.59	0.80	0.99	0.90	0.99	0.09	0.99	0.09
		Low risk of eutrophication	0.75	1.00	0.50	1.00	0.75	1.00	1.00	0.50
	High contribution to waste management	High treatment capacity	0.76	0.76	0.19	0.19	0.19	0.81	0.81	0.19
		Low residue generation	1.00	1.00	1.00	0.00	0.68	1.00	1.00	0.00
	High economic feasibility	High income-expenditure ratio	0.00	0.00	0.12	0.65	0.85	0.90	0.90	0.00

CALCULATING FINAL SCORES

Now, we need to calculate the aggregated score for each technology, considering weights and performances. Here, we suggest a method called the additive model. The additive model determines the value of a treatment technology as:

Equation 29

$$v^A = \sum_i^m w_x \cdot v_x^A$$

Where:

- v^A: value of the treatment technology A.
- m: number of main objectives (in this case 5)
- w_x: weight of main objective X.
- v_x^A:

  - For the main objectives, "high technical reliability" and "high economic feasibility", v_x^A is the normalised value of the performance of treatment technology A for one of the main objectives.

  - For the main objectives, "high contribution to waste management", "high social impact" and "high environmental protection", v_x^A is calculated using Equation 30.

Equation 30

$$v_x^A = \sum_i^m w_r \cdot v_r$$

Where:

- w_r: weight of sub-objective r (sub-objective of main objective X).
- v_r^A: normalised value of the performance of treatment technology A for sub-objective r.
- m : number of sub-objectives

Let us consider an example for a technology. Table 81 shows the normalised values of the performances of all treatment technologies for all objectives (from Table 80), as well as the average weights assigned to each objective and sub-objective (from Table 78).

Table 81: Normalised performances and weights for CSF

Objectives	Sub-objectives	Windrow Composting	In-vessel composting	Vermicomposting	AD	BSF	Slow Pyrolysis	Weight
Mains Objectives	High technical reliability	0.69	0.29	0.64	1.00	0.20	1.00	0.102
	High Social impact	Calculate using Equation 30						0.231
	High environmental protection							0.257
	High contribution to waste management							0.153
	High economic feasibility	0.00	0.00	0.12	0.65	0.85	0.90	0.257
High Social impact	Few working hazards	0.61	0.86	0.81	0.91	0.87	0.07	0.449
	Low nuisance level for community	0.10	0.24	0.31	0.89	0.17	0.10	0.163
	High job creation	0.50	0.38	0.00	0.00	0.50	0.75	0.236
High environmental protection	Low emission generation	0.59	0.80	0.99	0.90	0.99	0.09	0.588
	Low risk of eutrophication	0.75	1.00	0.50	1.00	0.75	1.00	0.412
High contribution to waste management	High treatment capacity	0.76	0.76	0.19	0.19	0.19	0.81	0.556
	Low residue generation	1.00	1.00	1.00	0.00	0.68	1.00	0.444

Example: What is the aggregated value for Windrow composting?

First, we need to calculate the aggregated values for those main-objectives composed of sub-objectives, using Equation 30:

- $v^{w.comp.}_{social\ impact} = w_{working\ hazards} \cdot v_{working\ hazards} + w_{nuisance} \cdot v_{nuisance} + w_{jobs} \cdot v_{jobs} = 0.449 \cdot 0.61 + 0.163 \cdot 0.1 + 0.236 \cdot 0.5 = 0.408$
- $v^{w.comp.}_{envir.protection} = w_{emissions} \cdot v_{emissions} + w_{eutrophication} \cdot v_{eutrophication} = 0.588 \cdot 0.59 + 0.412 \cdot 0.75 = 0.656$
- $v^{w.comp.}_{contributionWM} = w_{tret.cap.} \cdot v_{tret.cap.} + w_{residue} \cdot v_{residue} = 0.556 \cdot 0.76 + 0.444 \cdot 1 = 0.867$

Now, we can calculate the aggregated value for the treatment technology, using Equation 29:

- $v^{w.comp.} = w_{tech.rel.} \cdot v^{w.composting}_{tech.rel.} + w_{soc.imp.} \cdot v^{w.comp.}_{soc.imp.} + w_{envir.prot.} \cdot w^{w.comp.}_{envir.prot.} + w_{contr.WM.} \cdot v^{w.comp.}_{contr.WM.} + w_{econ.feas.} \cdot w^{w.comp.}_{econ.feas.} = 0.102 \cdot 0.69 + 0.231 \cdot 0.408 + 0.257 \cdot 0.656 + 0.153 \cdot 0.867 + 0.257 \cdot 0 = 0.466$

Scores will always range between 0 and 1. The same should be done for every technology. The final scores can be plotted for visualization, using a spreadsheet software (e.g. Excel). This is explained in the next section.

STEP 8: Displaying and interpreting results

How we illustrate results is important to how we convey our message. In this chapter we will learn some simple visualisations that can be used to show the results. This are the contents of this chapter.

First, let us have a look at the things that can be represented with illustrations:

- Weights given by individual stakeholders to the main objectives and sub-objectives
- Weights given by stakeholders from the same cluster
- Weights given by stakeholders from different clusters
- Normalised performance values per technology
- Final scores per technology considering weights given by one stakeholder
- Final scores per technology considering weights given by stakeholders from the same cluster
- Final scores per technology considering weights given by stakeholders from different clusters

Out of this list, normally only three points are relevant to summarise the entire evaluation exercise:

- Weights given by stakeholders from different clusters
- Normalised performance values per technology
- Final scores per technology considering weights given by stakeholders from different clusters

In the coming pages, the case of San Fernando City will be used to illustrate all these graphs.

WEIGHTS - ONE STAKEHOLDER

Plotting the preference of a stakeholder is interesting when you want to inform the stakeholder of the preferences he/she showed when doing the Swing and Reverse Swing methods. As an example, let us consider the same weights as the ones shown in Table 78. These are the average weights obtained through both methods, after checking that the rankings of the objectives and sub-objectives are equal and that the relative distances do not vary a lot. The weights given to the main objectives can be depicted using two types of charts: spider-webs and columns as shown in Figure 31.

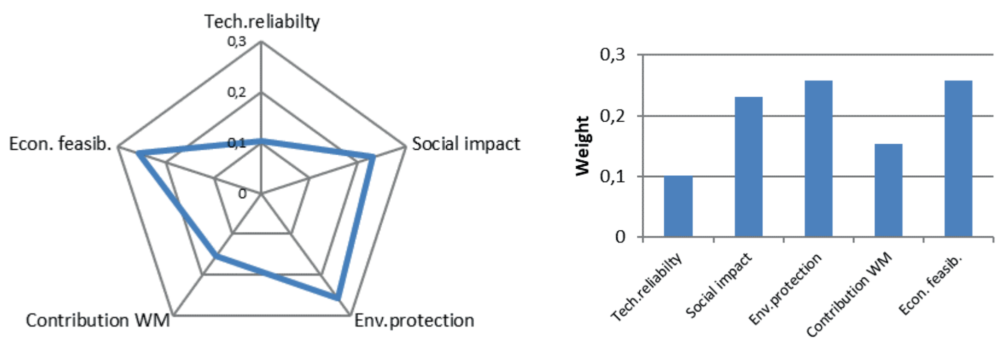


Figure 31: Weights given by a single stakeholder to five main objectives. Two chart types: spider web and columns

Based on the objective hierarchy considered in the manual, the number of sub-objectives under the same main objective is either two or three. Therefore, column charts are enough to present all variations. These are presented in Figure 32.

Note: although all sub-objectives have been presented in the same graph, they can only be compared if they share the same main-objective. It is, therefore, incorrect to conclude that the weight of the sub-objective "few working hazards" is lower than that of "low emission generation". These two sub-objectives were never assessed against each other and the weights of the main-objectives they refer to need to be considered in order to allow for comparison at the level of sub-objectives.

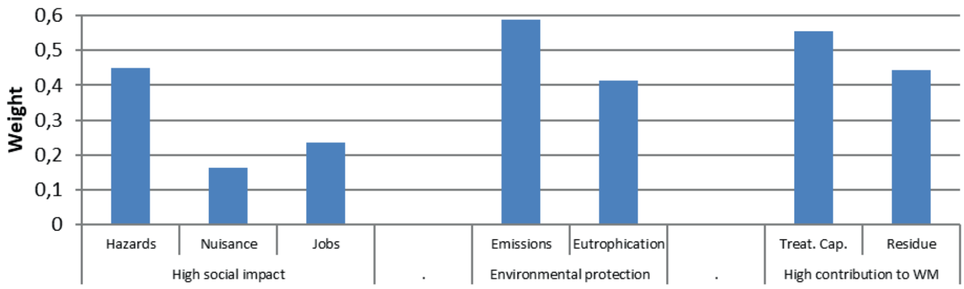


Figure 32: Weights given by a single stakeholder to the sub-objectives. Column chart

WEIGHTS – MULTI-STAKEHOLDER – SAME CLUSTER

In most studies, however, more than one stakeholder will participate, and they will most likely have divergent opinions. Compiling their opinions visually is, therefore, very important. This becomes clear when we look at the following weights given by 12 different stakeholders. These are the weights given by the Pollution Control Officers (PCOs) from the City of San Fernando. As explained in section "CSF – Case study (Step 2)", the PCOs are responsible for the accomplishment of the environmental ordinances of the municipality. Although all 12 stakeholders belong to the same stakeholder cluster, their preferences are not equal as can be seen in Table 82.

Table 82: Weights given to objectives and sub-objectives by 12 Pollution Control Officers (PCO) in CSF

		PCO-1	PCO-2	PCO-3	PCO-4	PCO-5	PCO-6	PCO-7	PCO-8	PCO-9	PCO-10	PCO-11	PCO-12
Main Obj.	Tech. reliabilty	0.10	0.20	0.14	0.15	0.08	0.15	0.14	0.08	0.01	0.13	0.03	0.06
	Social impact	0.23	0.20	0.21	0.16	0.26	0.19	0.22	0.29	0.15	0.19	0.24	0.31
	Env. protection	0.26	0.20	0.32	0.32	0.26	0.28	0.33	0.18	0.33	0.27	0.27	0.27
	Contrib. WM	0.26	0.20	0.22	0.20	0.23	0.23	0.17	0.34	0.37	0.20	0.30	0.20
	Econ. feasib.	0.15	0.20	0.10	0.17	0.16	0.15	0.15	0.11	0.14	0.21	0.15	0.16
High social impact	Hazards	0.45	0.34	0.36	0.23	0.39	0.38	0.23	0.33	0.43	0.34	0.38	0.25
	Nuisance	0.22	0.33	0.46	0.48	0.37	0.37	0.33	0.41	0.40	0.41	0.36	0.36
	Jobs	0.33	0.33	0.18	0.29	0.24	0.25	0.44	0.27	0.17	0.25	0.26	0.39
High env. protection	Emissions	0.59	0.50	0.59	0.72	0.35	0.58	0.42	0.71	0.84	0.79	0.49	0.73
	Eutro-phication	0.41	0.50	0.41	0.28	0.65	0.42	0.58	0.29	0.16	0.21	0.51	0.27
High contrib. to WM	Treat. Cap.	0.56	0.50	0.47	0.29	0.33	0.46	0.44	0.37	0.21	0.25	0.59	0.60
	Residue	0.44	0.50	0.53	0.71	0.67	0.54	0.56	0.63	0.79	0.75	0.41	0.40

How can we illustrate this information? Since the number of stakeholders is considerable (12), spider webs might not convey the information in a clear way (Figure 33). Furthermore, it is not possible to conclude which of the objectives is most important for the stakeholder group. Further statistical analysis is required.

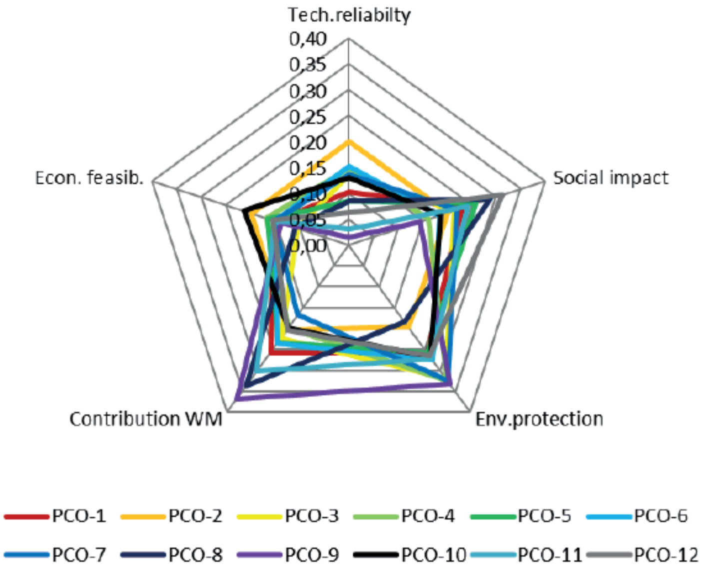


Figure 33: Spider web displaying the weights given by twelve Pollution Control Officers (PCOs) in CSF to the main-objectives

Boxplots or box-whisker diagrams are, in this case, useful to display these data. The line at the centre of the box is the median. The upper and lower limits of the box represent the range over which 50% of the values fall. Sticking out of the top and bottom of the box are two whiskers which extend to the maximum and minimum weights obtained. These types of boxes give us an idea of the variability of the weights given to one objective and also show which objectives are considered more important.

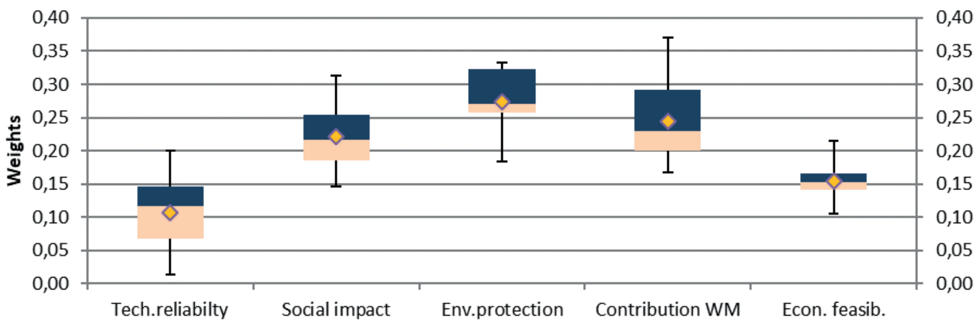


Figure 34: Boxplot displaying the weights given by twelve PCOs in CSF to the main-objectives. Average values are shown by the yellow dots. Median: line of the centre of the box. The upper and lower limits of the box: range over which 50% of the values fall. Upper and lower whiskers: maximum and minimum weights obtained.

According to the majority of the PCOs in the City of San Fernando, there is not clear consensus on which of the three objectives (i.e. "high environmental protection", "high contribution to waste management" or "high social impact") is the most important objective (Figure 34).

Although "high env. protection" has the highest average, some PCOs weighted "high contribution WM" higher (see the upper whisker). Besides, the median for "high contribution to WM" and "high social impact" are very close. Nevertheless, there is consensus (around 75% of respondents) on the fact that the objective "high technical reliability" is the least important, followed by "high economic feasibility".

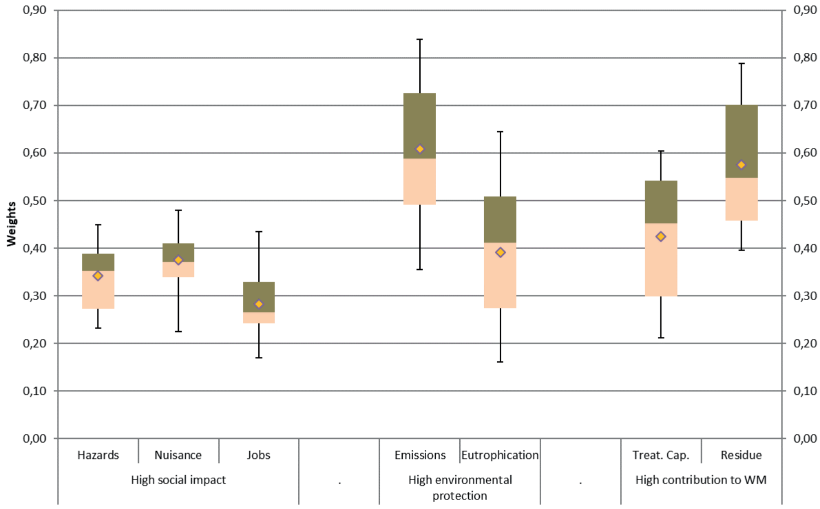


Figure 35: Boxplot displaying the weights given by twelve PCOs in CSF to the sub-objectives. Average values are shown by the yellow dots

As displayed in Figure 35, there is not much difference between the weights given to the sub-objectives of "high social impact"; therefore, no clear conclusion can be drawn about which of these sub-objectives is more valued. Emissions were, however, given more importance than eutrophication, and "low residue generation" was valued slightly higher than "high treatment capacity".

WEIGHTS – MULTI STAKEHOLDER – DIFFERENT CLUSTERS

Now that we have analysed the variability within one stakeholder cluster, let us have a look at how to assess the variability when different stakeholder clusters are considered. Figure 36 and Figure 37 are based on the weights given to the main objectives by the stakeholders shown in Table 83. The weights are provided in Annex 8.

Table 83: Stakeholder cluster and number of stakeholders per cluster interviewed in CSF

Stakeholder cluster	Number of stakeholders
City of Environmental & Natural Resource Office (CENRO)	6
City of General Service office (GSO)	6
NGO	6
Junkshop	7
Pollution Control Officers (PCO)	12

Figure 36 displays how each stakeholder cluster weighted each main-objective, whereas Figure 37 displays how each main-objective was weighted by each stakeholder cluster. In both figures, the inter-cluster variation of the preferences are shown by whiskers and sizes of the boxplots.

Figure 36: Weights of main objectives given by each stakeholder cluster in CSF

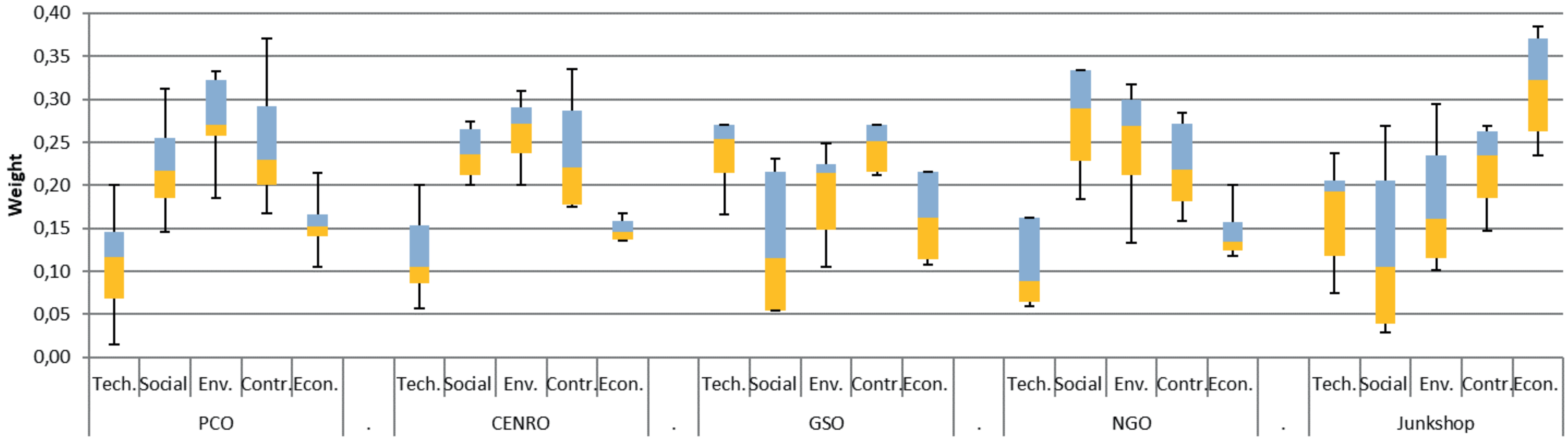


Figure 37: Weights given by each stakeholder cluster in CSF per main objective

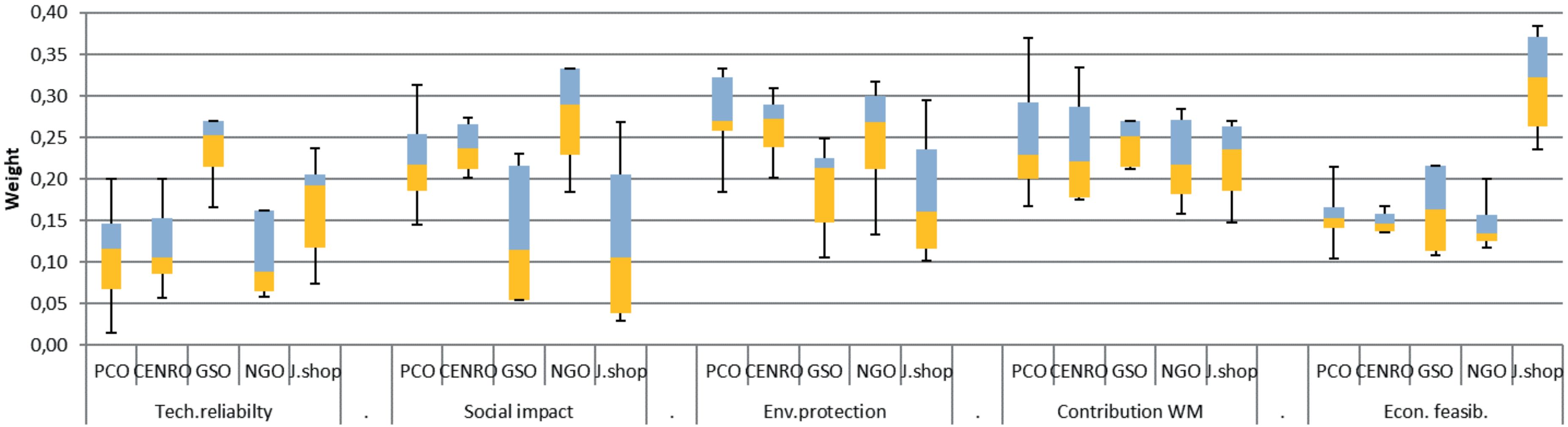


Figure 36 clearly shows that, in spite of the inter-cluster differences, each cluster presents some trends. The following conclusions can be drawn:

- The PCOs weighted "high environmental protection", "high contribution to WM" and "high social impact" highest. "High technical reliability" and "high economic feasibility" are scored lowest. This is understandable, since they are responsible for environmental matters in the barangays (districts) of the city. Low weights were given to "high technical reliability".

- The CENRO cluster also weighted "high environmental protection", "high contribution to WM" and "high social impact" highest. This is understandable, since they represent the environmental office of the city. The lowest weights were given to "high technical reliability". There is consensus on the weight given to "high economic feasibility".

- The GSO cluster weighted "high contribution to WM" and "high technical reliability" the highest. This is understandable, since they are responsible for the logistics of the SWM system in the city.

- The NGO cluster weighted "high social impact" and "high environmental protection" highest closely followed by "high contribution to WM". Low weights were given to "high technical reliability".

- The Junkshop cluster weighted "high economic sustainability" highest, which comes as no surprise since their business depends on the profit from dealing with waste materials.

Figure 37 clearly depicts how each main-objective was weighted by each stakeholder. The following conclusions can be drawn:

- "High technical reliability" is highly weighted only by the GSO, followed by the Junkshop cluster. These two stakeholders are aware of the logistics and the importance of having little downtime.

- "High social impact" is highly weighted by the NGO cluster, followed by the CENRO and PCO clusters. Some respondents in the GSO and Junkshop clusters also scored it high, but the medians of the clusters are considerably lower.

- "High environmental protection" is highly weighted by the PCO, CENRO and NGO clusters. The CENRO, however, shows more consistency within the cluster than the NGO (notice the smaller size of the boxplot and the shorter whiskers).

- All clusters, in general, gave similar weight to "High contribution to WM". Although some PCO and CENRO stakeholders weighted it higher, the GSO cluster shows the highest median and less variability within the cluster.

- "High economic sustainability" is highly weighted by the Junkshop cluster. All other clusters gave relatively low weights, a clear sign that they do not see Waste Management as a business.

In this manual, the analysis of the sub-objectives will not be elaborated. These can be evaluated by following the same process as explained above.

TECHNOLOGY PERFORMANCES

Spider webs are one good way of conveying the normalised performance values of the technologies. Have a look at Figure 38. The different technologies are represented by coloured lines, whereas the objectives and sub-objectives are the different axes. The scale is represented by the distance from the centre of the web to the tip of the axe. Remember that 1 represents the best score and 0 the worst score.

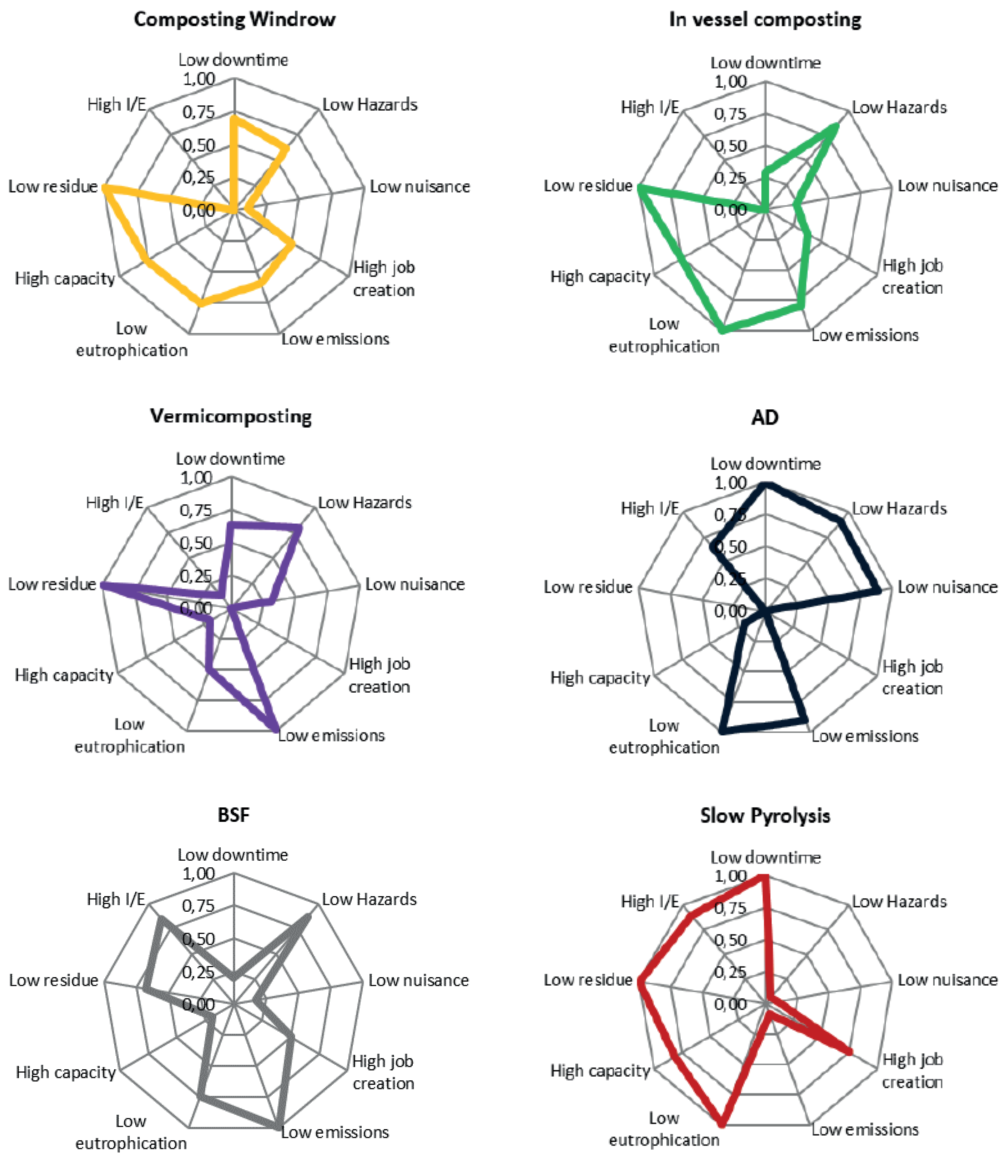


Figure 38: Spider web charts displaying the performances of five biowaste treatment technologies for different objectives and sub-objectives for the context of CSF

FINAL SCORES PER TECHNOLOGY– ONE STAKEHOLDER

Let us now plot the scores of each technology based on their performances and the weights given by a single stakeholder. First, the scores obtained by each technology need to be calculated using Equation 29 and Equation 30. Based on the data shown in Table 81, the scores shown are obtained for each technology.

Table 84: Scores obtained by each technology based on their performances and the weights given by a single stakeholder

	Scores
Windrow composting	0.47
In-vessel composting	0.51
Vermicomposting	0.48
Anaerobic digestion	0.65
Black Soldier Fly	0.65
Slow pyrolysis	0.64

The scores obtained by each technology can be depicted using two types of charts: spider-webs and columns as shown in Figure 39.

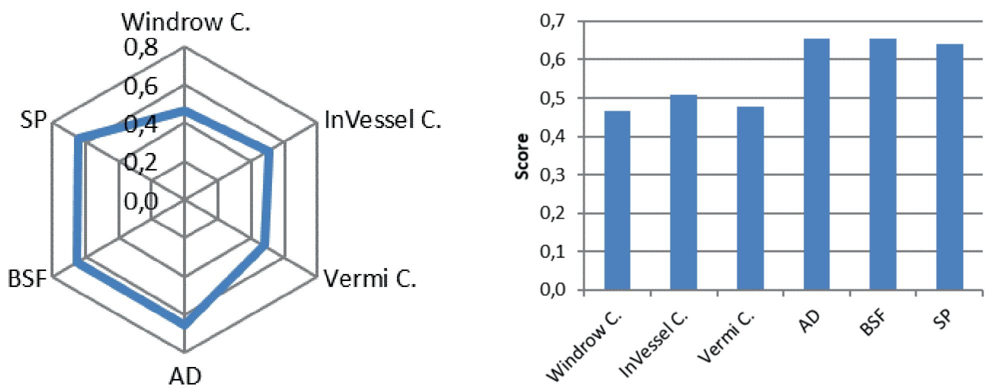


Figure 39: Scores obtained by each technology based on their performances and the weights given by a single stakeholder (spider web and bar-chart)

Based on the weights considered and the performances of the technologies for the context of CSF, anaerobic digestion and BSF are the technologies that score highest, closely followed by slow pyrolysis. The composting technologies obtained the lowest scores.

Step 8

FINAL SCORES PER TECHNOLOGY – MULTI STAKEHOLDER – SAME CLUSTER

In most studies, there will be more than one stakeholder, and they will most likely have diverging opinions that will result in different weights being assigned to each objective. Consequently, each technology will get a different score depending on whose weights are considered in the calculations.

How can this heterogeneity be aggregated and summarised?

Boxplots convey all this information in a condensed manner. Making use of a Spreadsheet, the scores per technology can be calculated for every stakeholder (Table 85) and then displayed as in Figure 40.

Table 85 Scores per technology based on weights given by 12 Pollution Control Officers (PCO) in CSF

	Windrow Composting	In-vessel composting	Vermi composting	AD	BSF	Slow Pyrolysis
PCO-1	0.57	0.61	0.53	0.61	0.62	0.66
PCO-2	0.53	0.51	0.49	0.66	0.57	0.73
PCO-3	0.58	0.63	0.58	0.68	0.61	0.63
PCO-4	0.55	0.57	0.6	0.67	0.65	0.64
PCO-5	0.56	0.61	0.53	0.63	0.63	0.69
PCO-6	0.57	0.59	0.56	0.66	0.61	0.68
PCO-7	0.55	0.58	0.5	0.67	0.62	0.71
PCO-8	0.59	0.63	0.57	0.54	0.59	0.63
PCO-9	0.62	0.71	0.7	0.53	0.73	0.6
PCO-10	0.52	0.54	0.58	0.65	0.66	0.64
PCO-11	0.56	0.64	0.5	0.58	0.62	0.65
PCO-12	0.51	0.56	0.49	0.6	0.62	0.58

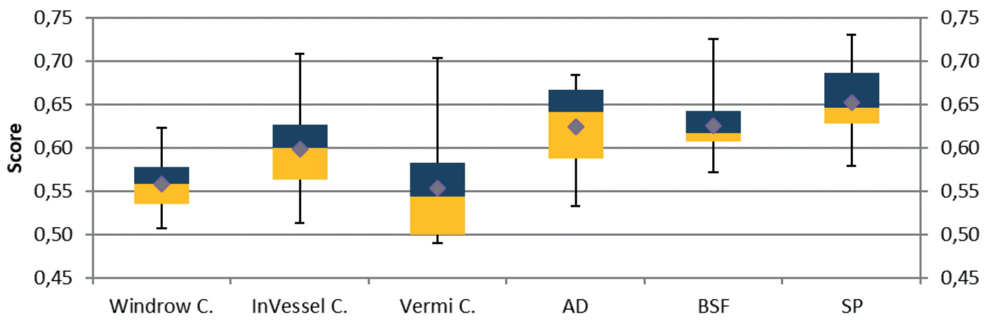


Figure 40: Boxplot and average values of scores per technology based on weights given by 12 Pollution Control Officers (PCO) in CSF

The following conclusions can be drawn based on Figure 40:

- Based on the average values, the ranking of technologies is: slow pyrolysis (0.65), BSF (0.63) AD (0.62), in-vessel composting (0.60), windrow composting (0.56) and vermicomposting (0.55).

- However, when looking at the medians, there is not much difference between slow pyrolysis (0.65) and AD (0.64), which are followed closely by BSF (0.62).

- In addition, based on the dispersion (height of boxes and length of whiskers), it is not possible to conclude that one or the other performs better.

- Vermicomposting obtained the lowest average score (0.55) and median (0.54) and, therefore, the lowest score, but also the biggest separation between the 1st and 3rd quartiles, implying the lowest agreement.

FINAL SCORES PER TECHNOLOGY – MULTI STAKEHOLDER – DIFFERENT CLUSTERS

After checking how to analyse the scores obtained by each technology based on their performances and considering the weights given by one stakeholder cluster, let us now have a look on how to display and interpret the variability in scores obtained when the weights from different stakeholder clusters are considered. Figure 41 and Figure 42 display the scores obtained per technology based on the weights given to the main objectives by the stakeholders shown in Table 83.

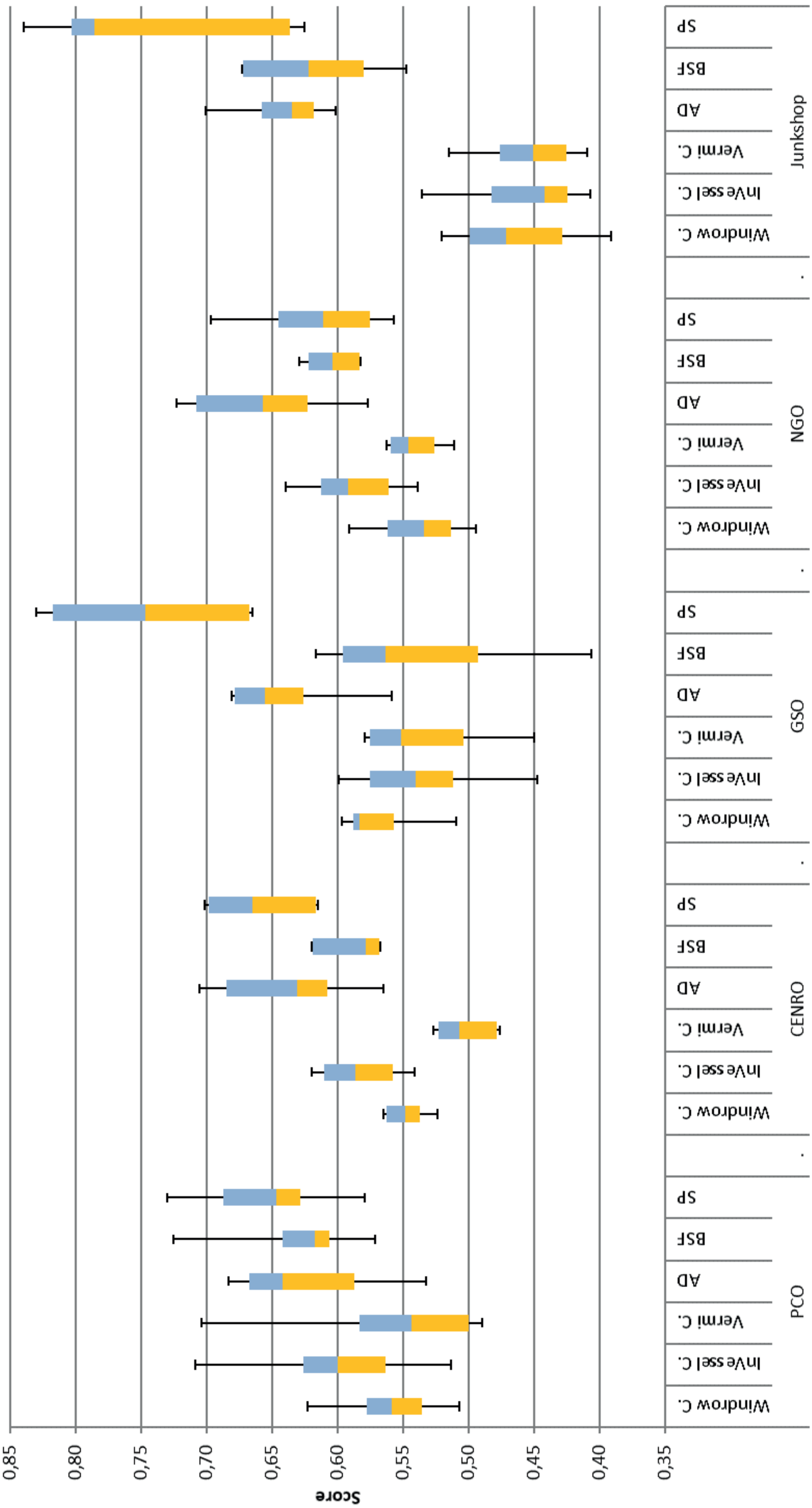


Figure 41: Scores obtained by each technology considering the weights given by different stakeholder clusters in CSF

Based on Figure 41, the following points can be concluded:

- Each stakeholder cluster yielded a different ranking of the technologies

- Scores based on PCOs' preferences:
  - There is not much difference between the median values of slow pyrolysis (0.65) and AD (0.64), which are followed closely by BSF (0.62)
  - Considering the dispersion (height of boxes and length of whiskers), it is not possible to conclude that any technology performs better than any other
  - The composting technologies scored slightly lower than the others
  - Vermicomposting obtained the lowest median score (0.54), but also showed the biggest separation between the 1st and 3rd quartiles, implying the lowest level of agreement

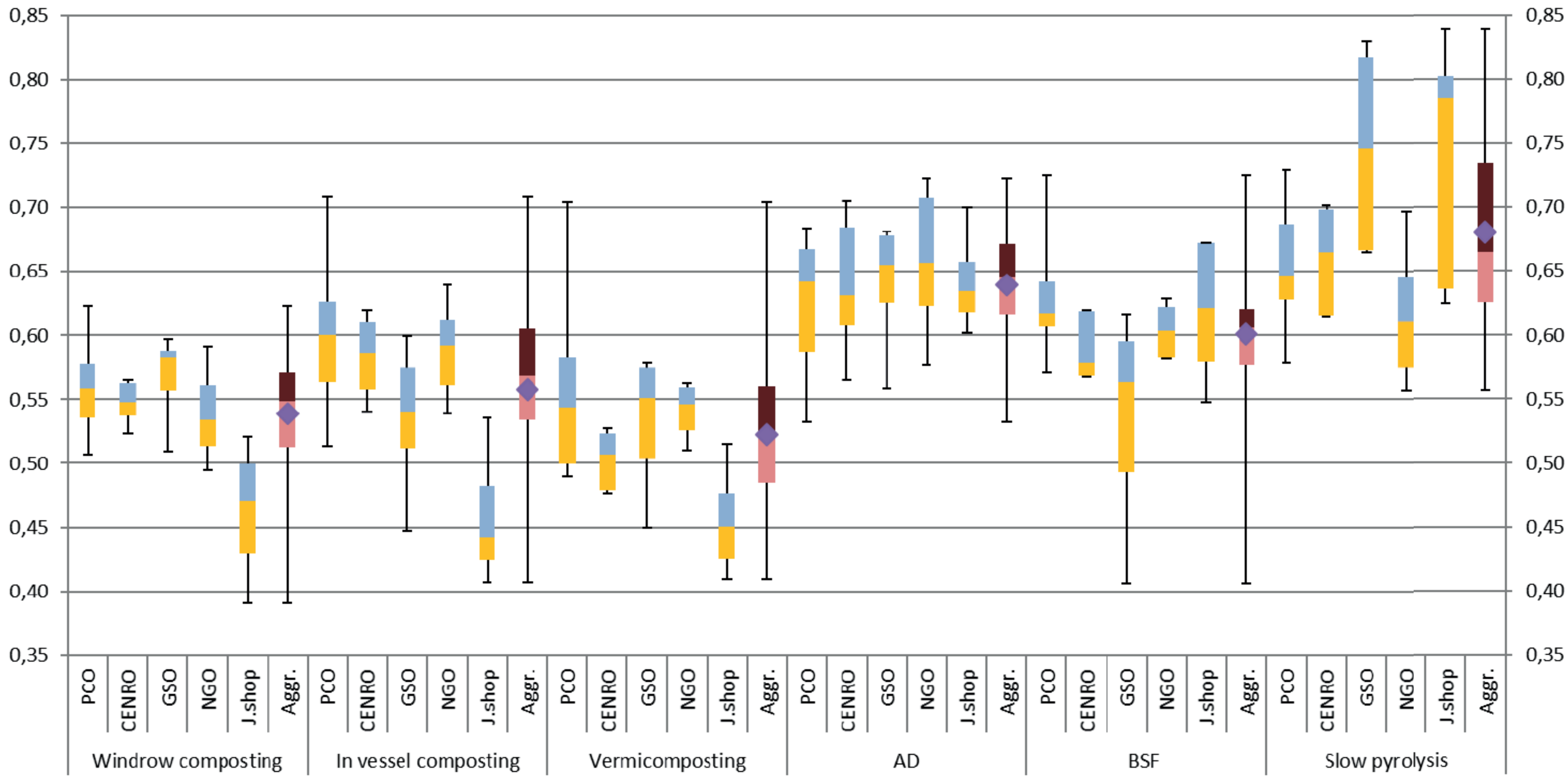
- Scores based on CENRO's preferences:
  - Slow pyrolysis and AD would obtain the highest scores, without much difference between each other (the boxplots overlay in the same range), although slow pyrolysis has a slightly higher median (0.67) than AD (0.63)
  - In-vessel composting and BSF follow thereafter. The boxplots also overlay and they have very similar medians (0.59 for in-vessel and 0.58 for BSF)
  - Vermicomposting would score worst, followed by windrow composting

- Scores based on GSO's preferences:
  - Slow pyrolysis is the clear winner, according to this cluster, followed by anaerobic digestion.
  - There is no significant difference among the scores obtained for the other technologies

- Scores based on NGO's preferences:
  - Although AD has a higher median (0.66), there is no important difference among the score ranges obtained by AD, slow pyrolysis, BSF and in-vessel composting
  - Windrow composting and vermicomposting would score lowest

- Scores based on Junkshops' preferences:
  - Slow pyrolysis obtained the highest median (0.79), and according to the weights of more than half of the respondents in this cluster, it would be the technology with the highest score
  - AD (0.64) and BSF (0.62) would be in second place, without a significance difference between them
  - The composting technologies would score significantly lower

Figure 42: Scores obtained based on the weights of different stakeholder clusters per treatment technology. Average scores per technology are depicted by the red squares



Based on Figure 42, the following points can be concluded.

- Considering the weights from all the stakeholders involved, which are shown on the aggregated scores for each technology, slow pyrolysis and AD would obtain the highest scores, followed by BSF. The composting technologies would rank the lowest

- The high scoring technologies would, therefore, satisfy the preferences of the majority of the stakeholders and obtain better performances under the characteristics of CSF

- Windrow composting:
  - This technology would not satisfy the preferences of the stakeholders. Based on the weights of most respondents, it obtained a score between 0.5 – 0.6
  - This was the technology that obtained the lowest score when the preferences of the Junkshop cluster were considered. It needs to be stated that "high economic feasibility" was highly weighted by this cluster, and composting scored lowest for that objective

- In-vessel composting:
  - This technology scored higher than windrow composting for some stakeholder clusters (PCO, CENRO and NGO), but lower for some others (GSO and Junkshop). This is probably because it scored higher for the environmental objectives, but lower for the technical reliability
  - All in all, the aggregated value for this technology is not significantly different to that of windrow composting.

- Vermicomposting:
  - This technology scored lower than the previous two for almost all respondents
  - In spite of performing better for "low nuisance" and "low emissions", it performs considerably worse for "high job creation" and "high treatment capacity", which out-performs the better performances obtained in the previous two sub-objectives.

- Anaerobic digestion:
  - This technology scored considerably higher than the composting technologies
  - The medians shown by all clusters are very similar, regardless of the different consensus levels observed within each cluster

- Black Soldier Fly processing:
  - This technology scored higher than the composting technologies, but lower than AD
  - This technology obtained the lowest scores based on the preferences of the GSO cluster. "High contribution to WM" and "High technical reliability" are the most important objectives for this cluster, against which this technology obtains low scores

- Slow pyrolysis:
  - This technology was very highly scored by the majority of the respondents in the GSO and Junkshop clusters. For the other clusters (PCO, CENRO and NGO), the scores obtained are not significantly different to those obtained by AD
  - The aggregated value of this technology is the highest of all

SCENARIOS

Once the previous analysis is conducted and the illustrations are ready, you might come up with some of the following questions:

- How much better could the best technology score if it would perform better for objective X?
- What if my second best technology would improve its performance for the objective in which it scored weakest? Would it then score better than the best technology?
- Why is the worst technology scoring so low? For which objectives did it perform poorly? Could that be improved?

These are interesting answers that call into question the final scorings, such as the one shown in Figure 42. Imagine that a technology scores poorly for the objective “high technical reliability” because there are no spare parts available in the case study. How much better would it score if spare parts could be ensured? Sometimes, it is worth spending a bit more time analysing the data in order to bring these type of issues to the surface.

We assume that preferences are more difficult to change than improving the performance for some objectives. Of course, the performance for some objectives will be impossible to change in the short term. For instance, if there is no market for compost, creating a demand will be very difficult. Similarly, the percentage of biowaste that is turned into residue per technology cannot be altered.

The performance for other objectives, however, could sometimes be improved. For instance, changing the characteristics of the available biowaste in order to increase the treatment capacity of a given technology, could be feasible depending on the context. Below, we provide some indications of how to proceed when such aspects need to be assessed. The case from CSF will be considered.

- First, the spider-webs (Figure 38) of the technologies should be re-checked and the objectives for which they perform poorest should be noted. This is done in Table 86; they are ordered according to the scores obtained.

Table 86: Objectives with the poorest performance per technology for the case of CSF

1. Slow Pyrolysis	2. AD	3. BSF
Low hazards (0.07)	High job creation (0.0)	Low downtime (0.2)
Low nuisance (0.1)	High capacity (0.19)	Low nuisance (0.17)
Low emissions (0.09)	Low residue (0.0)	High capacity (0.19)

4. In-vessel composting	5. Windrow composting	6. Vermicomposting
High economic f. (0.0)	High economic f. (0.0)	High job creation (0.0)
Low nuisance (0.24)	Low nuisance (0.24)	High economic f. (0.12)
Low downtime (0.29)		High capacity (0.19)

- Then, the objectives that are realistically improvable need to be identified. These are shown in Table 87.

Table 87: Feasibility of improving the performance for the worst performing objectives per technology in CSF

Technology	(Sub-) Objective	Feasibility	Current score	Adjusted Score
Slow Pyrolysis	Low hazards	**Feasible:** the low score is due to "contact with hot surfaces", "inhalation of gases" and "manual handling" (Table 30). Protection measures could be taken (gloves, masks).	(0.07)	0.4
	Low nuisance	**Partially feasible:** the low score is due to "inhalation of aerosols", "noise" and "odour" (Table 33). Reducing their impact implies high costs.	(0.1)	0.2
	Low emissions	**Not feasible:** implies high costs.	(0.09)	-
BSF	Low downtime	**Partially feasible:** the low score is due to "water" and "skills needed" (Table 57). Improving the availability of water requires big investments. Ensuring the skills needed is possible.	(0.2)	0.5
	Low nuisance	**Not feasible:** the low score is mainly due to "odour" (Table 33). Avoiding this implies big investments.	(0.17)	-
	High capacity	**Not feasible:** in this context, this is not possible due to the lignocellulosic nature of a big portion of the waste (coconut shells).	(0.19)	-
AD	High job creation	**Feasible:** hiring more people is possible. This will reduce the economic feasibility even more. Not ideal.	(0.0)	0.3
	High capacity	**Not feasible:** in this context, this is not possible due to the lignocellulosic nature of a big portion of the waste (coconut shells).	(0.19)	-
	Low residue	**Not feasible:** this technology will always generate digestate. Creating a market for it is not feasible in the short term.	(0.0)	-
In-vessel composting	High economic f.	**Not feasible:** creating a market for compost in the short term is considered not feasible.	(0.0)	-
	Low nuisance	**Not feasible:** the low score is mainly due to "odour" and "noise" (Table 33). Avoiding this implies big investments.	(0.24)	-
	Low downtime	**Partially feasible:** the low score is due to "water" and "spare parts" (Table 57). Improving the availability of water requires big investments. Ensuring the availability of spare parts is feasible.	(0.29)	0.5
Windrow Composting	High economic f.	**Not feasible:** creating a market for compost in the short term is considered not feasible.	(0.0)	-
	Low nuisance	**Not feasible:** the low score is mainly due to "pests", "odour" and "noise" (Table 33). Avoiding this implies big investments.	(0.24)	-
Vermi composting	High job creation	**Feasible:** hiring more people is possible. This will reduce the economic feasibility even more. Not ideal.	(0.0)	0.3
	High economic f.	**Not feasible:** creating a market for vermicompost in the short term is considered not feasible.	(0.12)	-
	High capacity	**Not feasible:** in this context, this is not possible due to the lignocellulosic nature of a big portion of the waste (coconut shells).	(0.19)	-

Based on the evaluation shown in Table 87, we conclude that Slow Pyrolysis is the technology for which most feasible improvements can be done. The performance of AD and vermicomposting for the objective "high job creation" were not changed due to their negative impact on the economic feasibility (higher labour costs). The improvements for BSF and In-vessel composting could not out-rank the scores of Slow pyrolysis with or without improvements. Figure 43 shows the potential scores that slow pyrolysis would obtain, if the improvements are applied (compare this graph to Figure 42). Based on the comparison of the aggregated scores per technology, it can be concluded that slow pyrolysis would perform best for the case of CSF.

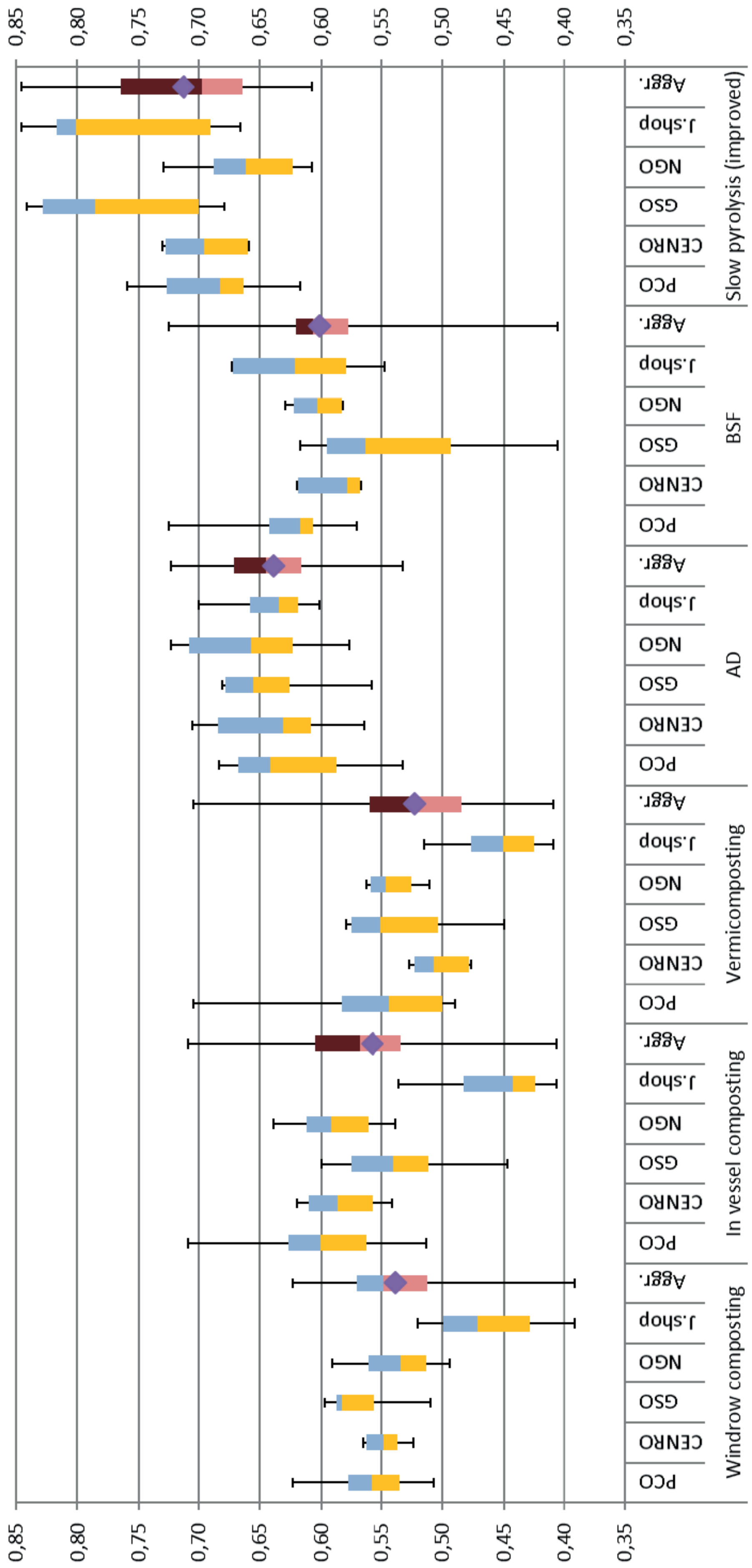


Figure 43: Scores obtained per technology. The scores of Slow Pyrolysis are adjusted

STEP 9: Final discussion

In this chapter, we will cover how to conduct the last exchange with the stakeholders. The goals of this final exchange are twofold. On the one hand, the person in charge of the assessment needs to share the final results of the study with the stakeholders involved, or representatives of each stakeholder cluster. The following information should be shared:

- Summary of the weights given by each stakeholder cluster (for the case of CSF, this is shown in Figure 36 and Figure 37)
- Summary of the performance of each technology for the given case study (for the case of CSF, this is shown in Figure 38).
- Summary of the scores obtained by each technology based on the weights and performances (for the case of CSF, this is shown in Figure 42).
- Newly created scenarios (as the ones at the end of the previous step) and the required adjustments to improve the performances for the given objectives.

One must guide the stakeholders in understanding the graphs. Some stakeholders might need time to really understand what each chart is conveying and how to look at it. Explain the parameters that are shown in the vertical and horizontal axes, as well as the units, if any. There is no point in showing graphs if the stakeholders are unable to interpret what is shown in them. If this is the case, simpler graphs might need to be prepared (normal column bars with the medians or average values instead of boxplots).

On the other hand, these exchanges are the most suitable moments to extract some final bits of relevant information from the stakeholders. At this point, we are interested in mainly two aspects:

- **Checking if the requirements for the newly created scenarios are feasible**
  If scenarios have been prepared, check with the local stakeholders whether the assumed changes are realistic and feasible. Consider that, as shown in the previous example, the performance of Slow pyrolysis could improve if masks and gloves were provided ("few working hazards"), or assume that the performance of in-vessel composting could be improved providing there is a supply chain for spare parts. Then, the availability of such items or the feasibility of starting such a supply chain would have to be checked. If not, these scenarios should be cancelled.

- **Identifying social acceptance issues**
  When explaining the scores obtained by each technology based on the weights and performances and when pointing out which technologies scored best, it is important to gather the reactions and opinions of the stakeholders. This is now when social acceptance issues might arise; they would be easily identifiable.

A technology might score very well for all objectives and still be rejected by some stakeholders or clusters of stakeholders. The reasons for this might go beyond the aspects considered in this manual (political pressure, distrust in the companies in charge, corruption, etc.). Therefore, if stakeholders blindly reject some of the technologies, the evaluator should identify the reasons for it, and note them. These aspects should be included in the final evaluation report of the assessment.

Annexes

Annex 1: City of San Fernando

The City of San Fernando (CSF) is the capital city of La Union Province and the regional centre of the Ilocos Region, located 270 km north of Metro Manila (see Figure 44). The city is sprawled along the foothills of the Cordillera Mountain range on the east and the South China sea to the west. The city covers an area of 10'699 ha and is still predominantly agricultural, although it already hosts several small and medium commercial and industrial enterprises, transportation hubs (land, air, sea) and tourist establishments.

Figure 44: Geographical location of CSF [Left: Seav (CC BY-SA 3.0), Right: TheCoffee (CC BY-SA 3.0)]

The City of San Fernando is politically subdivided into 59 barangays[4]. In 2015, when the SOWATT manual was tested, the city had 121'812 inhabitants (National Statistic Office Census, 2015), living in approximately 16'000 households, and a growth rate of 2.27%. Of the total population, the urban population was 82'389 or 72%, mainly concentrated in 25 barangays, while the rural population was 32'574 or 28%.

Due to its location in the tropics, the climate of CSF is characterised by two pronounced seasons: dry and wet season. The annual average temperature is 26.5°C, while the rainfall has an annual average of 2'577.6 mm (SWAPP, 2014).

[4] Municipalities and cities in the Philippines are divided into barangays, which are the smallest administrative and political division and are headed by elected officials. Together, these officials form a council which is considered to be a Local Government Unit (LGU).

PHYSICAL ELEMENTS

WASTE GENERATION AND CHARACTERISATION

Data regarding waste generation and characterisation in CSF was relatively easy to obtain. In 2012, the City Government ordered a WACS study (SWAPP, 2012), which aimed at updating the waste information in the Integrated Solid Waste Management plan 2004-2013. The data was also intended to project the future generation and disposal rates of the city. This study gave a general idea of the waste management situation in the city. Some of the main key findings are:

- Average per capita waste generation is 0.26 kg per day.
- Average per household waste generation is 1.30 kg per day.
- Of the total solid waste generated from households, 39% are biodegradables, followed by residual wastes with 32%, recyclables with 25%, and special waste with 4%.
- Total solid waste generated in the city is 45’937.4 kg per day (2012).
- About 69% of the wastes generated comes from the residential sector. Next, the biggest waste generators are the public market (10%), general stores (7.23%) and industries (5.47%).
- The city is expected to generate from 46.8 to 55.4 tons per day in the next 10 years (2013-2022).

Table 88: Biowaste fraction amounts collected from January to June 2013 in CSF (ton/month)

Biowaste fraction	Current use	Jan.	Feb.	March	April	May	June	Avg.	Variation (s.d.)
Banana peelings (market)	Sold in market	2.19	1.31	1.81	1.76	1.39	1.46	1.7	±0.3
Biodegradable (Barangays)	Landfill	9.32	10.19	6.64	14.49	26.16	15.48	13.7	±6.9
Biodegradable (city)	Landfill	9.49	1.89	1.26	0.47	5.88	1.93	3.5	±3.5
Biodegradable (private haulers)	Landfill	0.00	0.00	0.00	0.00	4.58	0.09	0.8	±1.9
Coconut meat (market)	Sold in market	1.24	1.55	1.44	2.00	1.49	1.77	1.6	±0.3
Coconut shell (Barangays)	Landfill	2.59	1.77	0.00	0.00	1.25	0.00	0.9	±1.1
Coconut shell (city)	Landfill	42.05	42.07	44.35	49.68	48.26	47.52	45.7	±3.3
Dried Coconut shell (market)	Sold in market	2.57	2.96	4.70	3.92	2.89	3.53	3.4	±0.8
Fish entrails (market)	Sold in market	2.18	2.33	2.51	2.76	2.26	2.20	2.4	±0.2
Food scrap	Landfill	3.72	3.97	2.32	2.23	2.63	0.00	2.5	±1.4
Market bio	Landfill	6.11	10.99	11.04	3.46	4.68	7.99	7.4	±3.2
Vegetable trimmings (market)	Sold in market	2.19	2.53	3.66	1.98	1.76	2.26	2.4	±0.7
Total (ton)		83.64	81.56	79.72	82.75	103.2	84.22	85.9	

WASTE COLLECTION

The formal waste collection system in 2014 combined public (City and barangay) and privately operated systems. The public City-based collection served the public market, the central business districts, major highways, other public areas, and in 2013, 9 barangays. The barangays' collection system collects the waste generated in the barangays.

Barangay-managed collection was encouraged and supported by the City, which gave subsidies to the barangays amounting to PHP 700 per day per truck (minimum 2 to 3 tons per day per truck) (SWAPP, 2014b). Consequently, since 2011, the City-based collection has decreased and has been transferred to the barangay-based waste collection as shown in Table 89.

Table 89: Share of coverage of city-based and barangay-based waste collection, 2011 – 2013

Number of barangays covered					
Year	**City-based**	**%**	**Barangay-based**	**%**	**Total**
2011[a]	26	57%	19	42%	45
2012[a]	27	57%	19	41%	46
2013[b]	9	19%	39	81%	48

a: GSO-SWEEP/City EMS Waste Management Committee
b: (SWAPP, 2014a)

As of the end of 2013, 39 barangays out of the total 59 barangays (representing 66%), were covered by barangay-based waste collection services. Waste collection in the barangays was handled by cluster barangays in which one barangay provided this service to several barangays. In 2013, there were 10 host barangays, servicing 38 cluster member barangays. Only one barangay was serviced by its own barangay-based waste collection. There were 11 barangays that were still not covered by waste collection services. These barangays were in the outlying areas of the city and houses were far from each other.

Collection frequency differed for different areas in the city. Wastes were collected daily in the central business district and two or three times a week for residential areas. Most of the barangays had regular waste collection schedules (two times a week, three times a week, or daily except for one rest day per week). There were some barangays where segregated collection is already implemented. Most of these barangays also imposed fees, with amounts ranging from PHP 20 to PHP 30 per month (SWAPP, 2012). In spite of having regular collection schedules in place, there were times when these were disrupted due to the breakdown of collection vehicles.

The LGU did not have a transfer station for its waste management. All wastes collected from waste sources were transported directly to the sanitary landfill of the LGU, whether collected by city, cluster or barangay (SWAPP, 2014b).

SOURCE SEPARATION

Waste segregation at source is perceived as very important to reduce waste disposed in the landfill, which in turn lengthens the lifespan of the landfill. Residents see the connection between waste segregation and its impact on the environment, as well as the advantages it brings to their health, safety and general welfare. Some inhabitants segregate their wastes for recycling ("make fertilisers out of composting"), reusing or selling ("source of extra income") and to help the City government in its efforts in the collection and disposal of waste.

The City Solid Waste Management Ordinance classifies solid waste into four types as specified in the Ecological Solid Waste Management Act of 2000. The City Ordinance also requires waste generators to segregate. Although there were barangays that already have ordinances on waste segregation and segregated collection, mixed waste collection is still the prevailing practise in the barangays. In 2014, only two barangays (Lingsat and Pagdalagan) strictly enforced the segregated collection of wastes (SWAPP, 2014b).

The City was planing on implementing the "No Segregation, No Collection" policy, as one of the biggest concern is the improper segregation of wastes. However, at the city level, segregation at source is not widely practised.

Different fractions of biodegradable waste were collected and brought to the landfill from the different barangays and the market of the city. The amount of biodegradable waste that was separately collected and quantified in the city in 2014 is shown in Table 88.

PHYSICAL ASSETS

The City LGU had six units of collection vehicles used to collect and transport waste from the city facilities (City Hall, Marcos Building, markets, slaughterhouses, City Plaza, parks, etc.), business establishments within the central business district and along the national highway. All these vehicles were regularly maintained. In 2014, four of them were still operational, while two were constantly having problems and undergoing repairs. Furthermore, the LGU has its own dumptruck (3 m^3) and bulldozer (3 m^3), which were used for SWM. For primary collection in the market, wheelbarrows and pushcarts were used. There were 36 utility workers employed for the SWM by the City LGU for sweeping in commercial areas. The barangays have their own street sweepers (SWAPP, 2012, 2014a).

WASTE TREATMENT

There was no treatment installation for mixed waste as such in CSF. Alternatively, the collected biodegradable waste from the market and from City-based collection areas was processed into compost in the composting facility located inside the sanitary landfill (SLF) compound. The facility hosted two shredders, two mechanical composting drums, one sieve, 140 bin composters and 13 vermicomposting beds. There were four to five employees hired to manage all organic waste collected. (GSO, 2014).

The waste not collected and remaining in the barangays was managed differently. Biowaste could either be fed to animals, burned (sometimes under fruit-bearing tress to induce fruiting), buried or thrown into canals or water bodies, especially when collection vehicles were out of order. In spite of truck collection and disposal in the landfill being the most common practises with biowaste from households, a survey conducted in CSF revealed that 70% of the respondents feed food waste or left-over food to animals, instead of putting them out for the scheduled collection trucks (SWAPP, 2014b). Coconut wastes (husks and shells) from the market were dried and used as fuel by the accredited informal waste sectors at the landfill (SWAPP, 2014b).

As for residual wastes, such as plastic bags, sachets (shampoo and condiments), styrofoam packaging, diapers and sanitary napkins, when not collected by the garbage crew, they were commonly burned, left anywhere, buried, thrown in rivers (especially when it rains) or sold when they had economic value. Some types of buried materials mentioned in surveys conducted in barangay Parian were light bulbs, dry cell batteries, spray canisters and expired drugs.

Recyclable wastes that can still be sold, such as tin cans/metals, paper/cartons, plastic containers, and glass/bottles, were sometimes also burned. Sixty percent of the respondents use paper waste as fuel for cooking, for instance (SWAPP, 2014b).

Programs for hazardous domestic waste management (e.g. cellphone batteries, used oil fluorescent lamps, etc.) and health care waste management were in place. Some of these wastes, such as busted lamps, were stored in a separate compartment within the SLF area for treatment and safe disposal by an authorised hazardous waste treater (SWAPP, 2014b). These waste types, however, were not covered in this report.

RESOURCE RECOVERY

The recycling infrastructure in CSF was well developed for waste fractions with an economic value, such as glass bottles, plastic containers, cartons, and tin cans. The city hosted three different types of activities for recycling: material recovery facilities (MRF), junkshops and informal recyclers or scavengers.

The MRFs were used for storage of recyclable materials and processing of biodegradable wastes. The recyclables stored in the MRFs come from the waste generators who put out their wastes at the curbside during the scheduled waste collection day. These were then collected by the barangay or cluster-barangay waste collectors and sent to the MRF for secondary sorting. When enough recyclables have been accumulated in the MRF, a junkshop picked up the segregated recyclables and pays the barangay/cluster barangay. The revenue from the sales of recyclables went to the barangay-cluster as income.

The volume of recyclable waste collected by the MRF seemed to decrease. The barangay waste collectors did not pay for these collected recyclables and the waste generators were not obliged to give them their recyclables. Besides, households were more aware that there is money in waste and, consequently, they no longer give their recyclables to the collection crew, but to itinerant waste buyers or directly to junkshops located within the city (SWAPP, 2014b).

Figure 45: Woman selling her recyclables to a junkshop

Although barangay MRFs were mandatory, as of 2012, there were still some barangays that did not have these. There were two cluster barangays with their own MRFs, serving eight barangays. Five individual barangays also had one MRF each in their respective barangays. Two barangays had accredited junkshops that operated as MRFs (SWAPP, 2012). Some schools also had MRFs and composting areas. The collected recyclables were sold to local junkshops.

Junkshops buy the regular recyclable materials like glass/bottles, metals, plastic containers, papers and cardboard/boxes from MRFs, itinerant waste pickers and from walk-in customers or sellers. Then, they sell these materials to bigger waste consolidators still within the City of San Fernando (except for glass bottles, which were sold outside the city). The buying price that they give per type of material is about 20% lower than the buying price of their consolidator-buyers, making it a profitable business.

Most of the recyclables generated within the City of San Fernando used to go directly to the local junkshops through its itinerant waste buyers and/or through their own collection system. There were 16 junkshops that were registered, but there were illegal or unregistered junkshops as well. The City has enacted a Junkshop Ordinance (City Ordinance No. 2004-001), which sets the requirements for the establishment of accredited junkshops in the City.

Figure 46: Entrance to a Junkshop

The third recycling activities were carried out by informal waste pickers. Some come regularly to the barangays to buy recyclables from households and establishments, whereas others collect recyclables from the landfill.

The City LGU did not have a central MRF for recyclables collected by the city-based collection crew. As there was no area for secondary segregation within the landfill, 19 accredited waste-picker families, who were allowed to work within the landfill, do the final sorting and recovery of materials in the active cell prior to the waste being disposed. Recovered recyclable materials were sold to an accredited junkshop, which complements their personal income. Food wastes recovered by the waste pickers were used as animal feed. The following table is an example of the type of materials diverted from the landfill on a monthly basis.

Table 90: Waste materials collected informally from the landfill in 2011 (CENRO, 2011)

Type of material	Weight (kg)	%Share
Recyclables	34’100	39.84%
Food Waste	1’625	1.90%
Coconut shell	30’955	36.16%
Leaves and other biodegradable wastes	16’120	18.83%
EcoSan Products	2’020	2.40%
Sharps	625	0.73%
Tires	115	0.13%
Busted Lights/Lamps	127 pieces	

Amounts recovered by non-accredited waste pickers are excluded.

WASTE DISPOSAL

The Engineered Sanitary Landfill covered an area of 10.6 hectares and is located in barangay Mameltac and barangay Dallangayan Oeste, about 4 km away from the city centre. It only accommodates municipal waste from CSF which amounted to around 48 metric tons daily. Its expected remaining lifespan was 12 years in 2014. This is a matter of concern for the municipality, as no other solution has been implemented so far.

Formerly, this area used to be a dumpsite. The conversion of the controlled dumpsite into an engineered sanitary landfill facility started in October 2005, under the Design-Built-Operate scheme (DBO) and funded by a World Bank loan (180 million PHP). The facility was designed for a lifespan of 25 years and it was built and operated by the joint venture (KCI-CRA). In October 2008, the operation of the landfill was turned over to the City Government. Presently, 18 City personnel were detailed for the operations and maintenance of the SLF. (CENRO, 2011)

The average daily disposal increased from 40.12 metric tons in 2008 to 48 mt in 2012, owing to the expansion of waste collection coverage, increasing commercial activities and frequent typhoons (SWAPP, 2014b). Most of the wastes (97.8 %) were disposed by city and barangay-based trucks. This was followed by private haulers that collect wastes generated in barangay Biday (by Timpuyog Junkshop) and barangay Cadaclan (by Jucar Construction). Other National offices, such as the Department of Health (DOH), regularly disposed of their waste to the SLF, contributing about 0.056% of the total. The wastes of other NGAs were also collected by the City Government and the barangays where the offices were located.

The waste disposed at the sanitary landfill contained 57% of biodegradable waste, 39% of residual waste and 4% of recyclable waste, while less than 1% or 0.02% were special wastes (SWAPP, 2009). Recyclable wastes that were disposed at the landfill were composed of paper (32.06%), plastic containers (29.71%), glass (21.35%), tin cans (9.24%) and some stones, rocks or sand that can still be used (3.38%).

Regular operating procedures were already being implemented, including the proper containment and management of wastes, collection and treatment of leachates, recovery and processing of recyclables and other materials, and the conducting of environmental monitoring activities. Every collection truck is weighted with an electronic truck scale upon arrival and once more after being emptied to determine the tare weight. Heavy equipment used for waste disposal at the landfill were a bulldozer, a landfill compactor, a hydraulic excavator, and a payloader. The facility operates from 8:00 AM to 5:00 PM from Sunday to Saturday and has six regular staff (one landfill manager and five helpers) and 20 waste (informal) pickers. It operated at a cost of ca. PhP 350,000 per month (SWAPP, 2009, 2014b).

GOVERNANCE ASPECTS

STAKEHOLDERS

Waste management services were the responsibility of the City Council and the barangays. Within the City Council, there were two departments sharing this responsibility: the Office of the City Environment and Natural Resource Officer (CENRO) and the Office of the City General Services Officer (GSO). In addition, there were other stakeholders also involved in the waste management system.

CENRO

The Office of the City Environment & Natural Resources Officer (CENRO) was in charge of the technical aspects related to waste management, such as planning, researches/studies, information, education and communication (IEC) and assessment. Among other non-waste related activities, the CENRO is in charge of:

- Developing and implementing plans and strategies to ensure the delivery of basic services and provision of adequate facilities relative to the environment and natural resources.
- Providing technical assistance and support to the City when dealing with issues mentioned in the previous point.
- Coordination with government agencies and non-governmental organisations when implementing measures to prevent and control land, air and water pollution.
- Active involvement in the renewal and rehabilitation of the environment during and after human intervention or natural disasters.
- Conducting IEC activities, such as lectures, discussions, sharing of good practices, contests on mural painting, demonstrations, research/study, posting of collaterals, house-to-house campaigns and participation in clean-ups. Information material was regularly produced, reproduced and disseminated to different target sectors.

Table 91 shows the number of people within the CENRO working on waste related activities in 2014, as well as their classification and whether they had training or not.

GSO

The Office of the City General Services Officer (GSO) was in-charge of the logistics part of solid waste management in the City. Among other non-waste related activities, the GSO is in charge of:

- Managing all waste facilities owned by the City and those granted to it in the form of donation, reparation, assistance and counterpart of joint projects
- Carrying out the waste collection
- Sweeping/cleaning of public areas
- Managing the sanitary landfill
- Disseminating information regarding prices, shipping and other costs of supplies commonly used by the city.

Table 91 shows the number of people within GSO working on waste related activities in 2014, as well as their classification and whether they had training or not.

Table 91: Inventory of LGU staff working on SWM (SWAPP, 2014b)

Function/Task Type of Service	Agency/ Department	Classification				With trainings	
		Permanent	Casual	Contractual	Job Order	Yes	No
SWM program management/IEC	CENRO	3		5	9	11	6
Collection and Transport	GSO						
• Driver		5			4	9	
• Collection crew		17			6	23	
Final Disposal	GSO						
• Landfill operation manager		1				1	
• Landfill personnel including composting/processing		8			1	9	
Street sweeping	GSO	12			9	21	
Septage Treatment Facility	CENRO			1	2	1	2

SWAPP

SWAPP is a leading non-profit multi-sectoral network of solid waste management (SWM) volunteers and practitioners whose aim is to empower local governments, communities, and the private sector towards a clean, safe and sustainable environment. The mission of SWAPP is to build the capacity of LGUs, communities, and the private sector to manage solid waste problems in their respective areas through research, training, technical assistance, information exchange, and network building. These were their main objectives:

- Enhance the knowledge and skills of SWM practitioners to plan and implement integrated solid waste management programs
- Disseminate information and promote exchanges and partnerships among SWM practitioners
- Advocate for policy reforms to strengthen LGU capacity to implement SWM programs

BARANGAYS

Barangays were the smallest administrative and political division and were headed by elected officials. Together, these officials form a council in which one of the members is always a Pollution Control Officer (PCO). The PCOs were responsible for the accomplishment of the environmental ordinances of the municipality. They were also in charge of supervising environmental related activities occurring within the barangay, which includes waste management (collection, MRF, cleaning and street sweeping, etc.).

JUNKSHOPS

Junkshop were private businesses which buy, store and sell recyclable material to other middlemen. They do some minor processing, such as sorting and pre-cleaning. In CSF, there were 16 accredited junkshops, but there were illegal or unregistered junkshops as well. The City has enacted a Junkshop Ordinance (City Ordinance No. 2004-001), which sets the requirements for the establishment of accredited junkshops in the City.

FINANCING

Financing municipal solid waste management activities in CSF is the responsibility of the municipality. Data from 2011 and estimations for 2012 could be consulted and were shown in Table 92.

Table 92: Financial data of CSF (SWAPP, 2014)

		2011	2012 (estimation)
Revenue generated in CSF	Property tax	371'599'381	325'383'550
	Internal revenue allotment	301'061'637	260'983'550
	Garbage fee	800'030	800'000
	Tipping fee (landfill)	104'000	50'000
Total Revenue		673'565'048	587'217'100
Budget for Environmental Protection and Management		4'390'000	4'025'000
Expenditures	General SW and Landfill	15'625'439	5'703'448
	Collection	2'424'100	300'000
Total expenditures		18'049'539	6'003'448

Revenue come from both internal and external sources. Internally, generated revenue includes the real property tax collected by the city. Garbage fees collected by the city from commercial and business establishments also goes to the general fund of the city. However, a WACS study revealed that only a few of the food establishments pay for the solid waste management of the LGU (PHP 30 per month). Included in the externally generated income is the Internal Revenue Allotment from the national government and the solid waste tipping fee for the use of the sanitary landfill of the city.

Revenue directly collected from waste related activities amounted to 904'910 in 2011 and 850'000 in 2012 (estimated). This covered 5% and 14.2% of the waste expenditures, respectively, and, consequently, almost the entire costs of waste activities had to be paid for with the general taxes. It seems that municipalities do not pay a separate waste fee and assumed this to be covered by the property tax. It remains unclear what the coverage rate of the property tax is in CSF.

Interestingly, the city of CSF foresaw a three-fold reduction of the general and landfill related expenditures and, consequently, the total expenditure figure for 2012 compared to 2011. Due to lack of data, this could not be corroborated. Furthermore, they also estimated that revenue collected from the tipping fees would be halved. Presumably, this is due to the reduction of waste that is disposed of in the landfill, which is the goal of the municipality.

POLICY AND REGULATIONS

Waste management in the city is shaped by the legal framework established by the National Government, which can be further transposed into local Ordinances, as the ones shown in Table 93. The Republic Act 9003, otherwise known as the Ecological solid Waste Management Act of 2000, was one of these national legal documents. It mandates all LGU to ensure a balanced environment for its constituents by implementing solid waste management at all levels, from barangays up to the provincial level. It also specifies that each city shall form a City Solid Waste Management Board (CSWMB). One of the activities of this board in CSF in 2014 had been to prepare the second 10 year SWM plan for the city.

As mentioned before, the barangays have specific responsibilities to undertake in coordination with the city solid waste management activities. After the issuance of DILG Memorandum Circular No. 2001-19 dated March 2, 2001, which required all barangays to create their respective Barangay Solid Waste Management Committees, all barangays of San Fernando City complied. Some of these have also enacted their own local ordinances on "Joint Integrated Waste Management Ordinance".

Table 93: Waste related ordinances in CSF (SWAPP, 2014)

Ordinance number	Title	Major components regarding SWM
City Ordinance No. 2003-007	An Ordinance providing for a Comprehensive Solid Waste Management in the City of San Fernando and for other purposes	Provisions for the system and procedure of SWM in CSF: Conducting IEC activities. Creation, and obligations of the CSWMB. Defining prohibited acts, penal provisions, enforcement mechanisms, incentives and monitoring & evaluation provisions.
City Ordinance No. 2004-001	An ordinance prescribing sanitary requirements for the operation of junk shops in the City of San Fernando	Permit requirements, health certificates, penalties and obligations of refuse collectors.
City Ordinance No. 2006-013	An ordinance enacting the Environment Code of the City of San Fernando, Province of La Union	Covers all ordinances, resolutions and related legislations relevant to the protection, conservation, utilization and management of the environment, specifically along the areas of land, water and air.
City Ordinance No. 2013-04	An ordinance regulating the use of plastic and Styrofoam in the City of San Fernando and providing penalties for violations thereof	Prohibition or limitations on the use and direct selling of plastic bags and Styrofoam.

Annex 2: Database of organic materials

Table 94 contains information on proximate analysis, carbon and nitrogen contents, as well as the calorific values of several organic materials. Most of the data originates from the database published by the Energieonderzoek Centrum Nederland (ECN, 2012), which contains a more extensive list than the one provided in this annex. The values shown in Table 94 should only be taken for guidance. Material can change their properties depending on the context. Particularly, the moisture content should be taken with care, since it fluctuates. Also, note that more than one observation is provided for some material. These materials change considerably from one context to the next.

Table 94: Physical and chemical characteristics of several organic materials

	Waste type	MC %	Ash $\%_{db}$	VS $\%_{db}$	FC $\%_{db}$	C $\%_{db}$	N $\%_{db}$	C/N	LHV_{db}	HHV_{db}	Ref.
Animal derived	Animal blood		1.4	93.8	4.8	50.5	13.8	3.7	21.6	23.3	[1]
	Animal fat	1.2				76.9	0.1	640.8	38.8		[1]
	Cow manure	90.0				3.1	0.2	18.0			[2]
	Horse manure	90.0				5.8	0.2	25.0			[2]
	Leather waste	14.1	5.0	66.4	14.5	49.3	12.4	4.0	16.6	18.5	[1]
	Poultry manure	95.0				4.7	0.3	15.0			[2]
	Sheep manure	75.0				20.6	0.9	22.0			[2]
	Swine slurry	92.0				6.0	0.3	20.0			[2]
Biowaste	Organic domestic waste -1		4.5			48.1	0.7	69.7	15.9	17.3	[1]
	Organic domestic waste -2	9.7	48.8	40.2	11.0	25.8	1.3	20.0	10.1	10.8	[1]
	Organic domestic waste -3	54.0	8.7			42.1	1.8	23.6	16.9	18.0	[1]
	Organic domestic waste -4	53.7	17.9			42.8	1.8	24.4	15.0	16.2	[1]
	Organic fraction MSW -1	16.7	53.4	36.1	10.5	34.4	1.7	20.4	14.4		[1]
	Organic fraction MSW -2	57.3	37.0	52.4	10.7	34.0	1.7	19.6	14.5		[1]
	Organic fraction MSW -3	65.0				9.6	0.2	50.7			[2]
Crop wastes	Bagasse -1	6.4	14.2			42.4	0.3	141.3			[1]
	Bagasse -2	8.4	7.7	79.6	12.7	45.2	0.2	226.0	17.0	18.2	[1]
	Bagasse -3	55.0	3.8	84.2	12.0	45.9	1.7	26.5	17.0	18.2	[1]
	Barley	6.2	4.3	76.8	18.9	45.9	0.4	106.7	16.9	18.1	[1]
	Barley straw	11.5	76.1	5.9	18.0	46.2	0.6	77.0	17.4	18.7	[1]
	Corn cob		1.4	80.1	18.5	46.6	0.5	99.1	17.5	18.8	[1]
	Corn stalks		6.4	73.3	20.3	43.9	1.3	34.3	17.0	18.3	[1]
	Corn stalks	8.0	7.0	73.4	19.5	44.8	0.9	52.7	15.8	16.9	[1]
	Corn stover	6.1	5.1	80.9	14.1	46.8	0.7	70.9	16.9	18.1	[1]
	Corn, shelled	9.0	1.4	77.9	20.7	41.7	1.1	37.9	15.1	16.6	[1]
	Maize		8.5			44.6	0.4	108.8	16.5	17.7	[1]
	Oat grain	11.0	3.1			47.6	2.2	21.6	17.7	19.9	[1]

	Waste type	MC %	Ash $\%_{db}$	VS $\%_{db}$	FC $\%_{db}$	C $\%_{db}$	N $\%_{db}$	C/N	LHV_{db}	HHV_{db}	Ref.
Crop wastes	Oat straw	30.0				35.3	0.7	48.0	17.7	18.9	[2] [1]
	Rice straw	7.0	16.8	66.6	16.6	39.8	0.9	42.3	13.6	14.7	[1]
	Rye straw		4.6			47.5	0.5	103.2	17.6	18.8	[1]
	Safflower straw		4.7	77.1	18.3	41.7	5.5	7.5	18.0	19.2	[1]
	Sorghum stalks	6.0	6.9	73.5	19.6	46.1	0.4	118.1	16.6	17.9	[1]
	Sugar cane bagasse	1.2		82.3	16.7	47.7	0.2	318.3	19.1		[1]
	Sugarcane fibre	71.8	15.7	71.6	12.7	44.5	5.2	8.6	5.0	17.7	[1]
	Sweet Sorghum	7.0	77.2	4.7	18.1	47.3	0.4	118.3	17.7	18.9	[1]
	Wheat grain	6.9	2.9			44.3	6.0	7.4			[1]
	Wheat straw	8.2	71.9	10.3	17.8	41.6	0.4	118.8	17.1	16.3	[1]
Food industry wastes	Bread	9.5	3.0	79.7	17.4	45.8	2.9	16.0	18.0	19.9	[1]
	Coffee grounds	60.0	0.2			30.0	1.0	30.0	10.6	12.6	[1]
	Coffee husk	10.0	2.5	83.2	14.3	49.4	0.8	61.0	19.1	20.4	[1]
	Empty Fruit Bunches palm oil	52.7	5.1			45.5	0.5	101.2	15.8	17.0	[1]
	Grain screenings	11.5	9.3			46.3	6.3	7.3	18.8	20.2	[1]
	Grape pomace		4.2	74.4	21.4	54.9	2.2	25.2	21.4	22.8	[1]
	Grape skins and seeds, air dried	6.3	6.0	66.1	27.9	48.3	1.9	25.0	18.5	19.8	[1]
	Grapefruit skin		4.5	65.8	29.7	54.1	6.9	7.8			[1]
	Litchi peel	62.3	4.2	68.0	27.8	45.1	1.0	47.0	17.9	19.3	[1]
	Mango peel	73.0	4.4	71.5	24.1	41.6	7.0	5.9	17.1	18.6	[1]
	Mango seeds	51.4	3.0	71.1	25.9	43.8	1.1	38.8	17.1	18.6	[1]
	Oil palm empty fruit bunch, pith	82.6	7.5	71.2	21.3	41.6	5.9	7.0	12.7	14.0	[1]
	Onion peel	13.2	14.1	69.7	16.2	38.2	0.6	67.1	14.7		[1]
	Orange peel and seeds	7.1	4.6	77.1	18.3	46.4	1.5	30.5	17.1	18.4	[1]
	Pineapple waste		4.4	78.8	16.8	47.3	1.1	41.9	17.2	18.5	[1]
	Soybean oil cake	9.5	7.0	76.6	16.5	38.8	6.6	5.8	13.5	14.9	[1]
	Spent coffee	50.4	0.7			59.7	1.6	37.5	23.7	25.5	[1]
	Tea waste		3.4			48.6	5.5	8.8	19.0		[1]
	Waste from brewing-industries		4.4			51.1	4.7	11.0	20.5	22.2	[1]
	Waste from malt-industries		6.0			45.1	4.7	9.6	17.5	19.0	[1]

	Waste type	MC %	Ash $\%_{db}$	VS $\%_{db}$	FC $\%_{db}$	C $\%_{db}$	N $\%_{db}$	C/N	LHV_{db}	HHV_{db}	Ref.
Other	Compost -1	11.6	8.7			49.4	0.5	91.5			[1]
	Compost -2	3.8	32.8			33.3	1.1	31.4			[1]
	Compost -3	35.7	29.0			37.7	1.2	32.8	15.8	15.1	[1]
	MSW Compost -1	34.3	50.2			20.7	1.3	16.3			[1]
	MSW Compost -2	25.6	39.7			33.8	1.8	18.5	13.2	14.0	[1]
	Water weed	96.0				1.6	0.1	21.0			[2]
Paper & cardboard	Cardboard -1		8.4	84.7	6.9	44.5	0.1	445.2	17.1	18.5	[1]
	Cardboard -2	5.4	10.9	79.1	10.0	38.0	0.3	151.8	14.6	15.6	[1]
	Magazines	5.0				31.3	0.1	466.6			[2]
	Mixed paper	6.0				40.7	0.2	173.0			[2]
	Newspaper -1	6.0				46.2	0.0	983.0			[2]
	Newspaper -2		1.0	88.5	10.5	51.6	0.1	468.9	18.2	19.5	[1]
	Paper -1	10.3	2.1	75.0	12.7	40.3	0.1	402.7	14.6	15.9	[1]
	Paper -2		8.6			49.0	0.5	109.0	22.6	24.3	[1]
	Paper, commercial office paper -3		3.5	82.7	13.8	45.0	0.1	346.0	17.4	18.8	[1]
Sludge	Digested activated sludge	75.0				7.4	0.5	15.7			[2]
	Raw activated sludge	75.0				8.8	1.4	6.3			[2]
Vegetables	Greenhouse waste (sweet pepper residues)	1.0	9.9	71.0	19.1	42.7	1.2	35.6		17.1	[1]
	Pepper waste	9.7	7.4	58.4	34.2	42.3	3.2	13.4			[1]
	Tomato plant, greenhouse waste	17.0	34.0	64.0	2.0	30.0	3.4	8.8	10.2	11.1	[1]
Woods	Sawdust	20.0				28.0	0.1	350.0			[2]
	Sawmill waste	25.0				16.6	0.1	169.2			[2]
	Wood	20.0				40.5	0.1	723.0			[2]

Annex 3: Validation of objectives

For the workshop "validation of objectives", you should print a list similar to the one shown below. This list contains all the main objectives and sub-objectives considered as default in the manual. In the list below, you will see that we included aspects not considered as objectives. This is because this workshop represents a good opportunity to extract information on the preferences of the local stakeholders. However, the master list could also only contain the objectives of the hierarchy.

MASTER LIST OF OBJECTIVES

Below, a master list of objectives for an organic waste treatment technology is provided. Please mark accordingly:

- **Column A:** write a tick, if you consider the objective important when choosing a technology.
- **Column B:** if you already wrote that objective in the previous paper, write the letter of that objective in column B.

A	B		
		1.	High technical reliability..
		2.	High social contribution to social wellbeing (social impact) ....
		3.	High environmental protection..
		4.	High contribution to waste management ....
		5.	High economic feasibility (economic profit)..
		6.	Low working hazards..
		7.	Low nuisance level for community..
		8.	High job creation..
		9.	Low generation of emissions to the atmosphere..
		10.	Low contamination risk of surface and groundwater (risk of eutrophication) ....
		11.	High treatment capacity (it can treat all the waste collected).........................
		12.	Low generation of non-marketable residue...
		13.	High acceptability of the technology on behalf of community ....
		14.	High organic fertilizer production..
		15.	High energy generation..
		16.	High level of mechanization..
		17.	Low level of mechanization...
		18.	Low space required..
		19.	High use of local materials for construction and maintenance.........................
		20.	....
		21.	....
		22.	....
			....

Annex 4: Adaptation to the Objective Hierarchy

EXAMPLE 1

Imagine the SOWATT manual is being applied by a private user. This private user owns a piece of land in a rural town in southern Bangladesh, where he cultivates some vegetables and crops. He does not make use of any type of fertilisers. He generates 10 kg of kitchen and garden waste per day. Until now, this waste was always buried in different holes he would dig somewhere in the land.

Adjacent to the piece of land, he owns a small house, where he lives with his wife. Their monthly salary allows them to buy the required monthly consumption of drinking water, but they cannot afford a constant supply of electricity, nor of cooking fuel. Furthermore, they are unable to afford a complete diet, in spite of all their vegetable production being for self-consumption.

The objective validation exercise (described in Step 4) revealed the following three aspects:

- Recovering nutrients that he could apply as fertiliser in his garden would contribute to an increase of food and would improve their food self-sufficiency.
- Energy generation would allow them to increase the number of hours they could have light at night.
- They are not bothered by any sorts of bad smell.

Is "recovery of nutrients" a means objective or a fundamental objective? In this particular case, the recovery of nutrients is just important. The goal is not to save money or to generate profit. For this farmer, more nutrients means having more crops and, therefore, having more food to eat. The same happens with energy generation. Both resources are for self-consumption and are not meant to save money or generate profit. This means that they are fundamental objectives. When checking if they would represent main objectives, or sub-objectives, we realize that both of them deal with recovering natural resources and, therefore, could be combined under the same main objective: "high recovery of resources".

On the other hand, in the objective validation exercise, the farmer clearly stated that "nuisance to community" will never be a problem for them. Assuming he double-checked this issue with his wife (as the second most important stakeholder in this particular case), that would mean we could remove the objective of "low nuisance level for community" from the objective hierarchy.

Based on these three aspects, the objective hierarchy had to be adapted as shown in Figure 47.

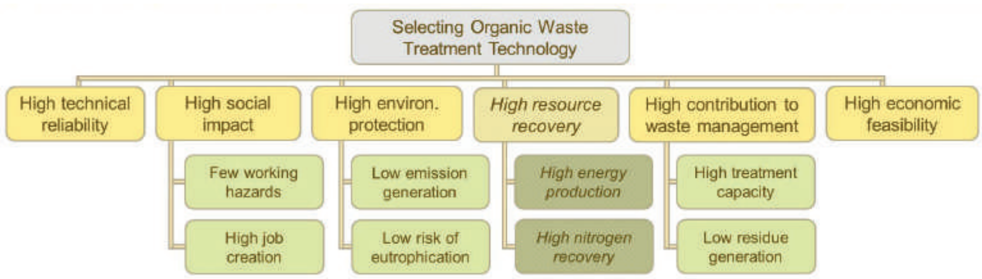


Figure 47: Adapted objective hierarchy (example 1)

The attributes for the new objectives would be as follows:

- High energy production: Mega Joules of energy generated per kg or ton of waste (MJ/kg or MJ/ton)
- High nitrogen recovery: % of input nitrogen recovered in the final product
- High phosphorus recovery: % of input phosphorus recovered in the final product.

In order to get the percentages of N or P recovered, some literature review needs to be done. Most of the times, the recovered percentages vary enormously depending on several factors (operational parameters, climate, general management, etc.). Therefore, each case would be different. In order to calculate the percentages, the following data is required:

- % of N or P content of biowaste before being treated expressed on wet or dry weight basis
- Total wet or dry weight of the biowaste before treatment
- % of N or P content of biowaste after being treated expressed on wet or dry weight basis
- Total wet or dry weight of the biowaste after treatment

These values need to be converted into the unit used for this attribute (% of N or P recovered in product). Below, it is explained how to do this:

Equation 31

$$\%N\ recovered = \frac{N_{at}(\%) * Weight_{at}(Kg)}{N_{bt}(\%) * Weight_{bt}(Kg)}$$

$$\%P\ recovered = \frac{P_{at}(\%) * Weight_{at}(Kg)}{P_{bt}(\%) * Weight_{bt}(Kg)}$$

Where:

- X_{at} = values after treatment
- X_{bt} = values before treatment.

Check that both numbers in the numerator must be given either in dry basis or wet weight basis.

Table 95: Estimated resource recovery values per technology

	Sub-objectives	Windrow Composting	In-vessel composting	Vermi composting	AD	BSF	SP
High resource recovery	**Percentage of input Nitrogen recovered in product (%N)**	25 - 91	62.5 - 91	40 - 91%	90 - 100	43	0 - 10
	Percentage of input P recovered in product (%P)	62 - 99	85 - 99	40 - 99%	95 - 100	67	100
	Energy per ton of waste treated (kWh/ton)	0	0	0	600 - 900	0	2’000 - 3’000

EXAMPLE 2

Now, imagine a municipality of 15´000 inhabitants in the Philippines where source segregation of organic waste has been implemented for 10 years. They collect 3.5 tons of biowaste per day. All this biowaste is currently taken to a poorly managed composting installation, where the leachate generated is threatening a nature reserve downstream.

The municipality heard of a new call for proposals published by the World Bank. The call intends to grant loans to a few municipalities so that they can build an appropriate biowaste treatment facility. These are the conditions set by World Bank:

- The municipalities need to at least collect three tons of source segregated biowaste per day.
- Depletion of phosphorus in the world is a matter of concern for the World Bank. Proposals including P recovery options will be favoured.
- Proposals with low investment costs will be favoured.

The municipality has hired a team of consultants to assist them in preparing such proposals. The consultants have applied the SOWATT manual and have realised that several changes are required in the objective hierarchy, considering the requirements specified by the World Bank.

The first objective pertains to the collection method and, therefore it is out of the scope of this manual. The second objective, however, deals with the recovery of resources. Why is the recovery of resources important in this case? This is due to the fact that we are dealing with depletable natural resources. When assessing where we could fit this in the existing objective hierarchy, the objective would naturally fit as a sub-objective of “High environmental protection”. The third objective deals with “high economic feasibility” and, therefore, can be included as a sub-objective. The validated Objective Hierarchy is shown in Figure 48.

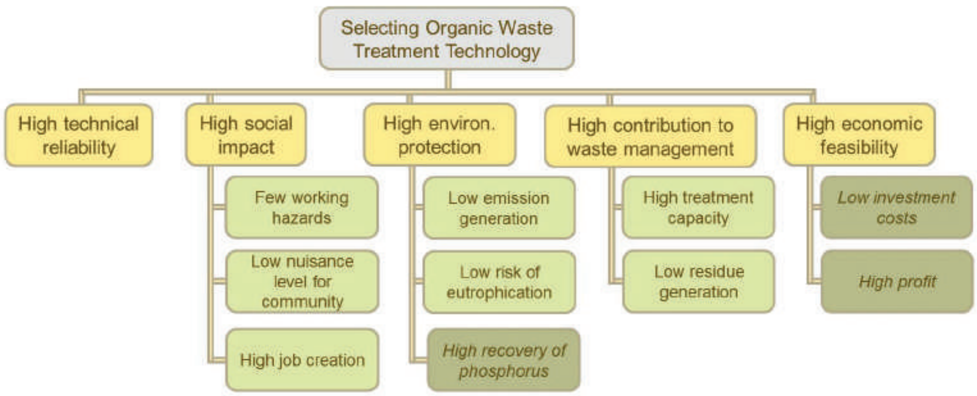


Figure 48: Adapted objective hierarchy (example 2)

The attributes for the new objectives would be as follows:

- High phosphorus recovery: % of input phosphorus recovered in the final product
- Low investment costs: Investment costs in USD of the treatment installation
- High profit: estimated Income expenditure ratio for a time span of 20 years

Annex 5: Water losses through evaporation during composting

This annex covers the methodology to calculate the water demands for the composting technologies. The methodology is based on Equation 32 (Robinzon et al., 2000).

Equation 32

$$W_{air}=m_{air}\cdot(\omega_{out}-\omega_{in})$$

Where:

- W_{air}: mass of water removed by natural ventilation
- m_{air}: mass of air
- ω_{out}: water content of the air leaving the composting pile. This is assumed to be saturated when leaving the pile at its temperature
- ω_{in}: water content of ambient air

In order to calculate W_{air} we first need to obtain the value for the other parameters. The flow of air is calculated from the oxygen consumption relationship. About 1.75 kg oxygen is required for the decomposition of 1 kg of biowaste. Using the total dry mass degraded (ΔM_{VS}), and assuming that all the oxygen in the air passing through the compost piles is consumed (oxygen content in the air ir reduced from 21% to zero), Equation 33 can be used to calculate m_{air}:

Equation 33

$$m_{air}=\frac{1.75\cdot\Delta M_{VS}}{0.2}$$

Where:

- ΔM_{VS}: mass loss of volatile solids during the composting process. Assumed to be 60%.

*This formula includes no correction for the oxygen supplied during turning.

In order to calculate ω_{out} and ω_{in}, first, the water vapour pressures at the corresponding two temperatures need to be calculated using Equation 34 (TET, undated-b). As for ω_{out}, the temperature value of the air coming out of the compost pile could range between 20°C (ambient temperature) and 70°C (in the case of windrow composting). For the sake of simplification, a temperature of 40°C was assumed. This air will be saturated with water. As for ω_{in}, the temperature of ambient air can also vary considerably. We recommend taking an average value for the day temperature per season. Next, based on the average Relative Humidity in the given context, the water content at ambient temperature will be calculated using Equation 35.

Equation 34

$$p_w = \frac{e^{77.3450+0.0057\text{-}7235/T}}{T^{8.2}}$$

*Units: p_w *(Pa) and Temp.in (K)*

Where:

- p_w: water vapour pressure (Pa)
- e : constant – 2.718…
- T : Temperature (K)

Equation 35

$$p_{w\text{-}in} = p_w \cdot RH \text{ (5)}$$

Next, using Equation 36 and Equation 37 (TET, undated-a), the units of ω_{out} and ω_{in} need to be converted into kg water/kg air since they now are in pascals (Pa).

Equation 36

$$\omega_{out} \left(\frac{kg_{water}}{kg_{air}}\right) = 062198 \cdot \frac{P_{w\text{-}out}}{(P_{atm} - P_{w\text{-}in})}$$

Equation 37

$$\omega_{in} \left(\frac{kg_{water}}{kg_{air}}\right) = 062198 \cdot \frac{P_{w\text{-}in}}{(P_{atm} - P_{w\text{-}in})}$$

Let us have a look at the following example. Table 96 shows the input data required for the exercise and Table 97 the information calculated.

Table 96: Required input data to calculate water loss through evaporation

Parameter	Value	Unit	Method
VS_{in}	500	kg/day	Based on context
VS_{out}	300	kg/day	60% of VS in
$T_{compost\ pile}$	313	K	Assumed to be 40°C
$T_{ambient}$	293	K	Based on context
RH	30	%	Based on context
P_{atm}	101’000	Pa	Based on context

Table 97: Calculated water loss through evaporation

Parameter	Value	Unit	Method
$p_{w\text{-}out}$	7'297	Pa	Equation 34 (T=313 K)
$p_{w\text{-}in}$	693	Pa	Equation 35
ω_{out}	0.05	kg/kg	Equation 36
ω_{in}	0.004	kg/kg	Equation 37
m_{air}	1'750	kg/day	Equation 33
ω_{air}	77.2	L/day	Equation 32

The amount of water lost through evaporation with an ambient temperature of 20°C and a relative humidity of 30% is around 77 L/day. Now, let us calculate how many litres we lose per ton of biowaste treated. This is calculated by Equation 38. Table 98 shows the amount of water loss for different TS and VS values of the feedstock.

Equation 38

$$\text{Water loss} = \frac{\omega_{air}}{VS_{in}/TS(\%)/VS(\%)/1000(kg/(ton)}$$

Table 98: Calculated water losses through evaporation for different TS and VS contents at ambient temperature 20°C and RH of 30%

		20	30	40	50	60	70	80
TS (%)	20	6.2	9.3	12.4	15.4	18.5	21.6	24.7
	30	9.3	13.9	18.5	23.2	27.8	32.4	37.1
	40	12.4	18.5	24.7	30.9	37.1	43.3	49.4
	50	15.4	23.2	30.9	38.6	46.3	54.1	61.8
	60	18.5	27.8	37.1	46.3	55.6	64.9	74.2
	70	21.6	32.4	43.3	54.1	64.9	75.7	86.5
	80	24.7	37.1	49.4	61.8	74.2	86.5	98.9

The water losses shown in Table 98 are the ones considered for windrow composting. In the case of in-vessel composting, the temperature of the air volumes leaving from and coming into the pile are more similar since the process occurs in a container. The relative humidity is also much higher. Consequently, less water is lost. The values used to estimate the range of in-vessel composting are shown in Table 99.

Table 99: Calculated water losses through evaporation for different TS and VS contents at ambient temperature 30°C and RH of 85% (In-vessel composting)

		20	30	40	50	60	70	80
TS (%)	20	3.6	5.4	7.2	9.0	10.8	12.6	14.4
	30	5.4	8.1	10.8	13.5	16.2	18.9	21.6
	40	7.2	10.8	14.4	18.0	21.6	25.2	28.8
	50	9.0	13.5	18.0	22.5	27.0	31.5	35.9
	60	10.8	16.2	21.6	27.0	32.4	37.7	43.1
	70	12.6	18.9	25.2	31.5	37.7	44.0	50.3
	80	14.4	21.6	28.8	35.9	43.1	50.3	57.5

As for vermicomposting, Table 100 shows the water losses in a conservative scenario. Remember that TS values are much lower in this treatment process.

Table 100: Calculated water losses through evaporation for different TS and VS contents at ambient temperature 20°C and RH of 40% (Vermicomposting)

		20	30	40	50	60	70	80
TS (%)	20	6.0	9.0	12.0	14.9	17.9	20.9	23.9
	30	9.0	13.4	17.9	22.4	26.9	31.4	35.9

Annex 6: Calculating size of an anaerobic digester

This Annex makes use of the example of San Fernando City to provide a step-by-step guide to determine the required size of an AD system to calculate the expected biogas production.

DAILY TOTAL BIOWASTE AVAILABLE AS FEEDSTOCK FOR AD

Based on the treatment capacity assessment, there are 930 kg of biowaste that can be treated through AD. Table 101 shows the properties of this waste.

Table 101: Suitable biowaste for AD in CSF

Biowaste fraction	Amount (ton/month)	Amount (kg/day)	Moisture (%)	VS (%)	C (%db)	N (%db)	C:N	Woody
Food and garden waste	27.9	930	55	80	39.6	1.75	22.6	No

This raw feedstock needs to be diluted with 3’500 L of water to achieve 90% moisture content. This will result in a slurry, which can be easily flushed into the digester. The daily total quantity of diluted feedstock, therefore, amounts to 4’430 L (using the approximation that 1 kg is equivalent to 1 litre).

HYDRAULIC RETENTION TIME (HRT)

The ideal HRT for a tropical climate with an average ambient temperature of 25–30°C is recommended to be around 30 days, which means that an active reactor volume of 133 m^3 is required (i.e. 4.43 m^3/day*30 days = 133 m^3). Several reactors combined are needed to achieve this volume.

FEEDSTOCK CHARACTERISTICS AND ORGANIC LOADING RATE (OLR)

The available biowaste (mix of vegetable, fruit and food waste) has a Total Solids (TS) content of 45%. In other words, of the 930 kg wet weight, 45%, which is equal to 418.5 kg, is dry matter. The Volatile Solids (VS) content of the dry matter is 80%, which means that the Volatile Solids amount is 335 kg and 83.5 kg is non-volatile solids. The balance of the biowaste is water, which does not contain Volatile Solids. Therefore, of the 4.43 m^3 of diluted feedstock, the share of Volatile Solids amount to 335 kg. This is equivalent to 75.6 kg VS/m^3 inflow (335 /4.43).

The Organic Loading Rate (OLR) can then be calculated as follows:

OLR=Q*S/ V

Whereby Q is the substrate flow rate (m^3 /day), S is the substrate concentration in the inflow (kg VS/m^3) and V is the reactor volume.

Therefore: OLR = 4.43 (m^3 /day)* 75.6 (kg VS/m^3)/133 (m^3)
= 2.5 kg VS per m^3 reactor volume and day.

An OLR below 2 kg VS/m^3 reactor volume and day is considered ideal for non-stirred AD systems. A higher OLR implies that a fraction of the biowaste will not be entirely digested when it exits the reactor.

SIZE OF THE AD SYSTEM

A fixed-dome digester (e.g. Nepali GGC2047 model) is designed so that 75% of the total reactor volume is used for the active slurry and 25% of the volume is used for gas storage. In this example, this means that the active volume of 133 m^3 (equals 75% of total) is complemented with 44.3 m^3 gas storage volume (25%), resulting in a total digester volume of 7.2 m^3 for the whole reactor.

BIOGAS AND METHANE YIELD

Taking into consideration that a mix of fruit/vegetable/food waste and garden waste typically yields biogas volumes of 0.35 m^3 /kg VS (assuming methane content of 60), it can be expected that approximately 116.4 m^3 of biogas is produced per day (2.5 kg VS/m^3 reactor and day*0.35 m^3 biogas yield per kg VS*133 m^3 reactor volume, equals to 116.4 m^3 /day). This is the biogas flow rate Q_{biogas}. Assuming that the biogas consists of 60% methane (CH_4), this gives a methane yield of 70 m^3 /day.

FUGITIVE EMISSIONS

If we assume that 3% of CH_4 is lost (Flesch et al., 2011), losses will amount to 2.1 m^3 /day. Assuming a density of 0.67 kg/m^3 (CDM), 1.4 kg CH_4/day are lost.

Annex 7: Swing method

Swing-method	Name Decis. Maker:	Interviewer:	Page:
	Project:	Date:	

Worst Alternative:

Points		High technical reliability	High social impact	High environmental protection	High contribution to waste management	High economic feasibility
0	**Best case scenario**					
	Worst case scenario	*75 days/year downtime*	*50% of hazards to workers* *80% of nuisance to community* *1 worker employed*	*400 kg CO_2 equivalent* *5 leachate risk*	*30% of collected waste can be treated* *100% wet waste weight as sub-product*	*0 Income expenditure ratio*

Alternative A:

Points		High technical reliability	High social impact	High environmental protection	High contribution to waste management	High economic feasibility
	Best case scenario	*0 day/year downtime*				
	Worst case scenario		*50% of hazards to workers* *80% of nuisance to community* *1 worker employed*	*400 kg CO_2 equivalent* *5 leachate risk*	*30% of collected waste can be treated* *100% wet waste weight as sub-product*	*0 Income expenditure ratio*

Alternative B:

Points

	High technical reliability	High social impact	High environmental protection	High contribution to waste management	High economic feasibility
Best case scenario		*10% of hazards to workers* *30% of nuisance to community* *5 workers employed*			
Worst case scenario	*75 days/year downtime*	↑	*400 kg CO_2 equivalent* *5 leachate risk*	*30% of collected waste can be treated* *100% wet waste weight as sub-product*	*0 Income expenditure ratio*

Alternative C:

Points

	High technical reliability	High social impact	High environmental protection	High contribution to waste management	High economic feasibility
Best case scenario			*0 kg CO_2 equivalent* *1 leachate risk*		
Worst case scenario	*75 days/year downtime*	*50% of hazards to workers* *80% of nuisance to community* *1 worker employed*	↑	*30% of collected waste can be treated* *100% wet waste weight as sub-product*	*0 Income expenditure ratio*

Alternative D:

Points

	High technical reliability	High social impact	High environmental protection	High contribution to waste management	High economic feasibility
Best case scenario				*70% of collected waste can be treated* *0% wet waste weight as sub-product*	
Worst case scenario	*75 days/year downtime*	*50% of hazards to workers* *80% of nuisance to community* *1 worker employed*	*400 kg CO_2 equivalent* *5 leachate risk*	↑	*0 Income expenditure ratio*

Alternative E:

Points

	High technical reliability	High social impact	High environmental protection	High contribution to waste management	High economic feasibility
Best case scenario					*2 Income expenditure ratio*
Worst case scenario	*75 days/year downtime*	*50% of hazards to workers* *80% of nuisance to community* *1 worker employed*	*400 kg CO_2 equivalent* *5 leachate risk*	*30% of collected waste can be treated* *100% wet waste weight as sub-product*	↑

Sub-objectives for main objective: High social impact

Worst Alternative:

Points

0

	Few working hazards	Low nuisance level for community	High job creation
☺			
☹	*50% of hazards to workers*	*80% of nuisance to community*	*1 worker employed*

Alternative A:

Points

	Few working hazards	Low nuisance level for community	High job creation
☺	*10% of hazards to workers*		
☹	↑	*80% of nuisance to community*	*1 worker employed*

Alternative B:

Points

	Few working hazards	Low nuisance level for community	High job creation
☺		*30% of nuisance to community*	
☹	*50% of hazards to workers*	↑	*1 worker employed*

Alternative C:

Points

	Few working hazards	Low nuisance level for community	High job creation
☺			*5 workers employed*
☹	*50% of hazards to workers*	*80% of nuisance to community*	↑

Sub-objectives for (main) objective: High environmental protection

Worst Alternative:

Points

Points
0

	Low emission generation	Low eutrophication impact
☺		
☹	*400kg CO_2 equivalent*	*5 leachate risk*

Alternative A:

Points

Points

	Low emission generation	Low eutrophication impact
☺	*0kg CO_2 equivalent*	
☹	↑	*5 leachate risk*

Alternative B:

Points

Points

	Low emission generation	Low eutrophication impact
☺		*1 leachate risk*
☹	*400kg CO_2 equivalent*	↑

Sub-objectives for (main) objective: High contribution to waste management

Worst Alternative:

Points

0

	High treatment capacity	Low residue generation
☺		
☹	*30% of collected waste can be treated*	*100% wet waste weight as sub-product*

Alternative A:

Points

	High treatment capacity	Low residue generation
☺	*70% of collected waste can be treated*	
☹	↑	*100% wet waste weight as sub-product*

Alternative B:

Points

	High treatment capacity	Low residue generation
☺		*0% wet waste weight as sub-product*
☹	*30% of collected waste can be treated*	↑

Annex 8: Reverse Swing Method

Reverse Swing-method	**Name Decis. Maker:**	**Interviewer:**	**Page:**
	Project:	**Date:**	

Worst Alternative:

Points

100

	High technical reliability	High social impact	High environmental protection	High contribution to waste management	High economic feasibility
Best case scenario	*0 day/year downtime*	*10% of hazards to workers* *30% of nuisance to community* *5 workers employed*	*0 kg CO_2 equivalent* *1 leachate risk*	*70% of collected waste can be treated* *0% wet waste weight as sub-product*	*2 Income expenditure ratio*
Worst case scenario					

Alternative A:

Points

	High technical reliability	High social impact	High environmental protection	High contribution to waste management	High economic feasibility
Best case scenario		*10% of hazards to workers* *30% of nuisance to community* *5 workers employed*	*0 kg CO_2 equivalent* *1 leachate risk*	*70% of collected waste can be treated* *0% wet waste weight as sub-product*	*2 Income expenditure ratio*
Worst case scenario	*75 days/year downtime*				

Alternative B:

Points

	High technical reliability	High social impact	High environmental protection	High contribution to waste management	High economic feasibility
Best case scenario	*0 day/year downtime*	↓	*0 kg CO_2 equivalent* *1 leachate risk*	*70% of collected waste can be treated* *0% wet waste weight as sub-product*	*2 Income expenditure ratio*
Worst case scenario		*50% of hazards to workers* *80% of nuisance to community* *1 worker employed*			

Alternative C:

Points

	High technical reliability	High social impact	High environmental protection	High contribution to waste management	High economic feasibility
Best case scenario	*0 day/year downtime*	*10% of hazards to workers* *30% of nuisance to community* *5 workers employed*	↓	*70% of collected waste can be treated* *0% wet waste weight as sub-product*	*2 Income expenditure ratio*
Worst case scenario			*400 kg CO_2 equivalent* *5 leachate risk*		

Alternative D:

Points

	High technical reliability	High social impact	High environmental protection	High contribution to waste management	High economic feasibility
Best case scenario	*0 day/year downtime*	*10% of hazards to workers* *30% of nuisance to community* *5 workers employed*	*0 kg CO_2 equivalent* *1 leachate risk*	↓	*2 Income expenditure ratio*
Worst case scenario				*30% of collected waste can be treated* *100% wet waste weight as sub-product*	

Alternative E:

Points

	High technical reliability	High social impact	High environmental protection	High contribution to waste management	High economic feasibility
Best case scenario	*0 day/year downtime*	*10% of hazards to workers* *30% of nuisance to community* *5 workers employed*	*0 kg CO_2 equivalent* *1 leachate risk*	*70% of collected waste can be treated* *0% wet waste weight as sub-product*	↓
Worst case scenario					*0 Income expenditure ratio*

Sub-objectives for main objective: High social impact

Worst Alternative:

Points

100

	Few working hazards	Low nuisance level for community	High job creation
☺	*10% of hazards to workers*	*30% of nuisance to community*	*5 workers employed*
☹			

Alternative A:

Points

	Few working hazards	Low nuisance level for community	High job creation
☺	↓	*30% of nuisance to community*	*5 workers employed*
☹	*50% of hazards to workers*		

Alternative B:

Points

	Few working hazards	Low nuisance level for community	High job creation
☺	*10% of hazards to workers*	↓	*5 workers employed*
☹		*80% of nuisance to community*	

Alternative C:

Points

	Few working hazards	Low nuisance level for community	High job creation
☺	*10% of hazards to workers*	*30% of nuisance to community*	↓
☹			*1 workers employed*

Sub-objectives for (main) objective: High environmental protection

Worst Alternative:

Points

100

	Low emission generation	Low eutrophication impact
☺	*0 kg CO_2 equivalent*	*1 leachate risk*
☹		

Alternative A:

Points

	Low emission generation	Low eutrophication impact
☺	↓	*1 leachate risk*
☹	*400 kg CO_2 equivalent*	

Alternative B:

Points

	Low emission generation	Low eutrophication impact
☺	*0 kg CO_2 equivalent*	↓
☹		*5 leachate risk*

Sub-objectives for (main) objective: High contribution to waste management

Worst Alternative:

Points

100

	High treatment capacity	Low residue generation
☺	*70% of collected waste can be treated*	*0% wet waste weight as sub-product*
☹		

Alternative A:

Points

	High treatment capacity	Low residue generation
☺	↓	*0% wet waste weight as sub-product*
☹	*30% of collected waste can be treated*	

Alternative B:

Points

	High treatment capacity	Low residue generation
☺	*70% of collected waste can be treated*	↓
☹		*100% wet waste weight as sub-product*

Annex 9: Weights from CSF

This annex presents the weights obtained in CSF. These weights were considered throughout Step 8.

Table 102: Weights given through the Swing and Reverse Swing method by the 12 PCO-s

		PCO-1	PCO-2	PCO-3	PCO-4	PCO-5	PCO-6	PCO-7	PCO-8	PCO-9	PCO-10	PCO-11	PCO-12
Main Objectives	Tech.reliabilty	0.102	0.200	0.137	0.149	0.085	0.153	0.135	0.083	0.014	0.130	0.030	0.063
	Social impact	0.231	0.202	0.214	0.163	0.258	0.185	0.220	0.287	0.145	0.188	0.242	0.313
	Env.protection	0.257	0.196	0.320	0.323	0.258	0.276	0.325	0.185	0.333	0.268	0.273	0.266
	Contribution WM	0.257	0.204	0.224	0.199	0.234	0.235	0.168	0.337	0.370	0.200	0.303	0.203
	Econ. feasib.	0.153	0.198	0.105	0.166	0.165	0.151	0.153	0.108	0.137	0.214	0.152	0.155
High social impact	Hazards	0.449	0.337	0.364	0.233	0.390	0.381	0.231	0.327	0.426	0.339	0.377	0.254
	Nuisance	0.225	0.333	0.455	0.480	0.369	0.373	0.333	0.408	0.405	0.411	0.358	0.355
	Jobs	0.326	0.330	0.180	0.288	0.241	0.246	0.435	0.265	0.170	0.250	0.264	0.391
High environmental protection	Emissions	0.588	0.503	0.588	0.718	0.355	0.579	0.417	0.714	0.839	0.788	0.487	0.729
	Eutrophication	0.412	0.497	0.412	0.282	0.645	0.421	0.583	0.286	0.161	0.212	0.513	0.271
High contribution to WM	Treat. Cap.	0.556	0.504	0.474	0.287	0.333	0.461	0.444	0.373	0.212	0.253	0.588	0.604
	Residue	0.444	0.496	0.526	0.713	0.667	0.539	0.556	0.627	0.788	0.747	0.412	0.396

Table 103: Weights given through the Swing and Reverse Swing method by the 6 CENRO stakeholders

		CENRO-1	CENRO-2	CENRO-3	CENRO-4	CENRO-5	CENRO-6
Main Objectives	Tech.reliabilty	0.200	0.137	0.057	0.102	0.096	0.108
	Social impact	0.225	0.274	0.262	0.248	0.201	0.216
	Env.protection	0.250	0.274	0.284	0.310	0.201	0.270
	Contribution WM	0.175	0.178	0.255	0.186	0.335	0.270
	Econ. feasib.	0.150	0.137	0.142	0.155	0.167	0.135
High social impact	Hazards	0.292	0.385	0.360	0.286	0.286	0.286
	Nuisance	0.333	0.385	0.400	0.238	0.476	0.476
	Jobs	0.375	0.231	0.240	0.476	0.238	0.238
High environmental protection	Emissions	0.526	0.526	0.556	0.526	0.526	0.526
	Eutrophication	0.474	0.474	0.444	0.474	0.474	0.474
High contribution to WM	Treat. Cap.	0.526	0.909	0.556	0.667	0.526	0.526
	Residue	0.474	0.091	0.444	0.333	0.474	0.474

Table 104: Weights given through the Swing and Reverse Swing method by the 6 GSO stakeholders

		GSO-1	GSO-2	GSO-3	GSO-4	GSO-5	GSO-6
Main Objectives	Tech.reliabilty	0.167	0.231	0.263	0.243	0.270	0.270
	Social impact	0.177	0.231	0.211	0.054	0.054	0.054
	Env.protection	0.249	0.212	0.105	0.216	0.162	0.216
	Contribution WM	0.240	0.212	0.263	0.270	0.216	0.270
	Econ. feasib.	0.168	0.115	0.158	0.216	0.108	0.216
High social impact	Hazards	0.476	0.455	0.556	0.476	0.556	0.500
	Nuisance	0.310	0.318	0.278	0.381	0.278	0.350
	Jobs	0.214	0.227	0.167	0.143	0.167	0.150
High environmental protection	Emissions	0.412	0.667	0.375	0.474	0.444	0.556
	Eutrophication	0.588	0.333	0.625	0.526	0.556	0.444
High contribution to WM	Treat. Cap.	0.298	0.444	0.474	0.526	0.556	0.412
	Residue	0.702	0.556	0.526	0.474	0.444	0.588

Table 105: Weights given through the Swing and Reverse Swing method by the 6 NGO stakeholders

		NGO-1	NGO-2	NGO-3	NGO-4	NGO-5	NGO-6
Main Objectives	Tech.reliabilty	0.162	0.067	0.162	0.067	0.059	0.111
	Social impact	0.184	0.333	0.243	0.333	0.294	0.286
	Env.protection	0.239	0.133	0.270	0.267	0.294	0.317
	Contribution WM	0.284	0.267	0.189	0.200	0.235	0.159
	Econ. feasib.	0.142	0.200	0.135	0.133	0.118	0.127
High social impact	Hazards	0.432	0.337	0.364	0.318	0.409	0.350
	Nuisance	0.351	0.465	0.455	0.455	0.455	0.500
	Jobs	0.216	0.198	0.182	0.227	0.136	0.150
High environmental protection	Emissions	0.588	0.667	0.588	0.667	0.444	0.556
	Eutrophication	0.412	0.333	0.412	0.333	0.556	0.444
High contribution to WM	Treat. Cap.	0.556	0.333	0.556	0.333	0.556	0.412
	Residue	0.444	0.667	0.444	0.667	0.444	0.588

Table 106: Weights given through the Swing and Reverse Swing method by the 7 Junkshop stakeholders

		Junkshop-1	Junkshop-2	Junkshop-3	Junkshop-4	Junkshop-5	Junkshop-6	Junkshop-7
Main Objectives	Tech.reliabilty	0.074	0.118	0.148	0.194	0.237	0.192	0.206
	Social impact	0.268	0.206	0.111	0.065	0.105	0.038	0.029
	Env.protection	0.102	0.294	0.185	0.161	0.132	0.115	0.235
	Contribution WM	0.185	0.147	0.185	0.258	0.263	0.269	0.235
	Econ. feasib.	0.370	0.235	0.370	0.323	0.263	0.385	0.294
High social impact	Hazards	0.526	0.526	0.435	0.500	0.455	0.391	0.455
	Nuisance	0.395	0.211	0.174	0.200	0.182	0.174	0.182
	Jobs	0.079	0.263	0.391	0.300	0.364	0.435	0.364
High environmental protection	Emissions	0.833	0.667	0.526	0.667	0.667	0.625	0.714
	Eutrophication	0.167	0.333	0.474	0.333	0.333	0.375	0.286
High contribution to WM	Treat. Cap.	0.354	0.667	0.526	0.667	0.667	0.625	0.714
	Residue	0.646	0.333	0.474	0.333	0.333	0.375	0.286

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Municipal solid waste continues to be a challenge for municipal authorities, and finding best practices and appropriate solutions for its management is of great interest to municipal officers.

Municipal organic waste, also called biowaste, constitutes the main fraction of municipal solid waste in low- and middle-income settings. Often, more than 50% of all municipal solid waste is organic and easily biodegradable. Illegal and uncontrolled disposal of solid waste that contains a high percentage of biowaste leads to the generation of methane (a potent greenhouse gas), as well as landfill leachate, that may pollute groundwater and surface water. Finally, biowaste, if managed inappropriately, attracts animals and disease vectors and, thus, puts human health at risk.

Whereas in the past, the priority of waste management was the collection and removal of waste with subsequent disposal, the importance of resource recovery and recycling is attracting more attention and priority. Along with this increasing paradigm change focusing on resource recovery, new approaches for the management of biowaste with respective treatment technologies are becoming more popular (e.g. composting, anaerobic digestion, black soldier fly processing, vermicomposting, etc.). We developed the SOWATT manual: **S**electing **O**rganic **W**aste **T**reatment **T**echnologies to help structure and assist in the process of comparing and selecting the most promising biowaste treatment options for a given case study.

The underlying concept of this manual is that biowaste has a value and that recycling biowaste can contribute to the economic and environmental sustainability of solid waste management.