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Decentralized Composting Analysis Model—Benefit/Cost Decision-Making Methodology

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Abstract: Municipal solid waste management is considered one of the major environmental challenges. Organic waste, especially food waste, usually accounts for over 50 wt% of municipal solid waste, yet, in most countries, it is the least recovered material. Decentralized composting aims to develop a new framework of waste management, building a closed-loop system for the composting of home, community, and commercial organic waste in urban environments. However, in some cases, decentralized composting is not economically and/or environmentally viable. Even when it is viable, various barriers and challenges need to be addressed in many cases. Different models in the literature address certain aspects of organic waste management, such as food waste treatment technology, recovery of energy, site selection, or environmental impact. The objective of this study is to provide guidelines and a methodological framework to quantify economic, social, operational, environmental, and regulatory aspects, in order to examine the viability and feasibility of decentralized composting projects at any given location. The decentralized composting analysis model proposed in this study has been developed with an innovative approach to decentralized composting project planning and design, an approach that is both holistic and very practical. The innovative model incorporates various aspects to examine the viability of decentralized composting projects based on benefit/cost criteria. In this respect, a result obtained through another model that examines a specific aspect of decentralized composting can be used as input for the model presented here. The decentralized composting analysis model provides a powerful tool for decision makers, based on the quantification of the decentralized composting project characteristics, and a benefit/cost index that takes into account the various impact variables. The decentralized composting analysis model allows examining the viability of the decentralized composting project in different scenarios, locations and options, and can help indicate the most viable alternative. In this paper, we describe the decentralized composting analysis model and its methodological framework, along with numerical examples to demonstrate its implementation.

Keywords: benefit/cost; compost; decentralised composting analysis model; environmental regulation; municipal solid waste; organic waste management

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1. Introduction

Over the past few decades, municipal solid waste management (MSWM) has been considered one of the major environmental challenges [1–4]. Organic waste (OW), especially food waste, is usually the most significant component of municipal solid waste [5,6], and its reduction has been ranked 3rd of 100 solutions to reducing climate change [7]. However, in most countries, it is the least recovered material [8–10]. According to Eurostat [11], about 17% of the municipal waste in the EU-27 countries was composted in

2018. In countries belonging to the Organisation for Economic Co-operation and Development (OECD), composting is also relatively uncommon compared to other treatment and disposal methods. The municipal waste by-treatment operations in OECD countries are presented in Figure 1. In countries in Europe and the Mediterranean, OW usually accounts for about 35 wt%–57 wt% of the MSW; thus, the treatment of OW has received increased attention for over two decades [12], and there has been growing attention to improving its management [5,6,8,13–16]. One prominent approach for treating organic waste is decentralized composting (DC) [13,17]. Despite the relevance of DC, the research developed worldwide on the subject does not address, for the most part, many aspects involved with such projects—technical, environmental, social, and economic [17]—but rather addresses certain aspects of OW management, such as treatment technology [18–20], recovery of energy/organic fertilizer [21], plant site selection [22], or environmental/life-cycle impacts [23,24].

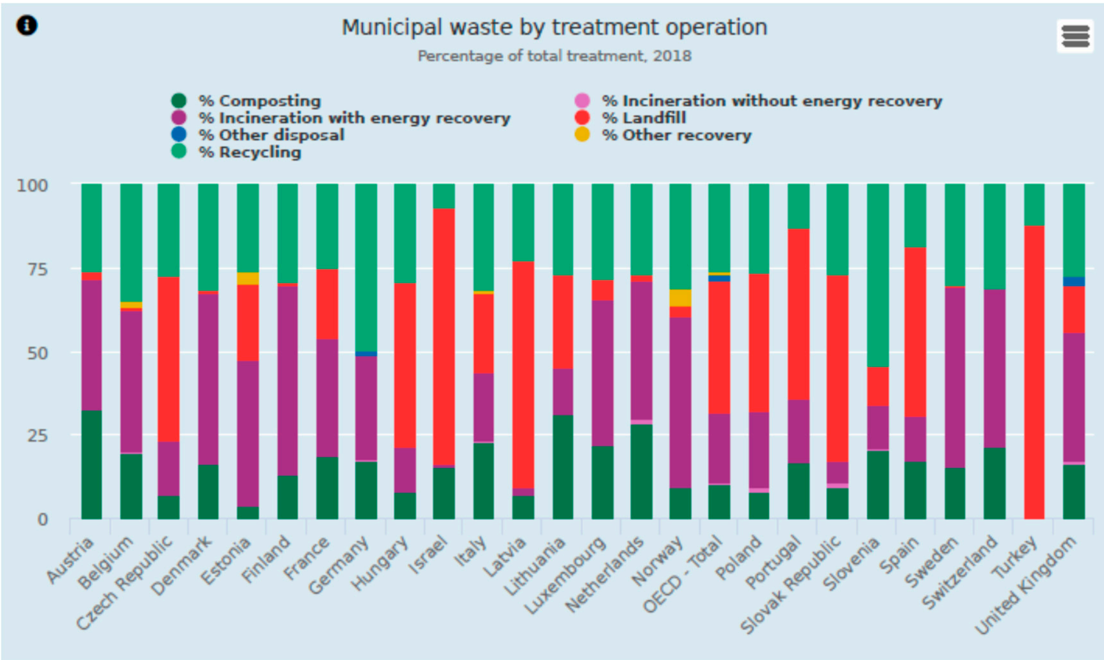

Figure 1. OECD municipal waste by treatment operation in 2018. Source: OECD (2020) [15].

OW management solutions should be analysed in an integrative manner by considering economic, social, operational, environmental, and regulatory aspects [1,2,17,25–28]. In this paper, we present a decentralized composting analysis model (DCAM) that takes those aspects—economic, social, operational, environmental, and regulatory— into account to examine the viability and feasibility of decentralized composting projects at any given location.

The innovation in the DCAM presented in this paper is that it incorporates various aspects, and examines the viability of DC projects, based on benefit/cost criteria. In this respect, results obtained through other models that examine specific aspects of DC—such as technologies, for example—can be used as input for the DCAM presented here.

2. Decentralized Composting

Decentralized composting (DC) aims to develop a new framework of waste management, build a closed-loop system of OW valorisation, and integrate decentralized home, community, and commercial composting systems [13,27]. DC also has the potential to reduce landfill volumes, save on collection, transportation, and treatment costs, and reduce conventional emissions as well as greenhouse gases, mainly methane [5,8,13,27]. In addition, OW management in the community is important in terms of education for sustainability and environmental protection, especially if the products of the process are used by the local community, to grow local edible plants for example. A schematic illustration of organic waste composting is presented in Figure 2.

Figure 2. Schematic illustration of organic waste composting.

The DCAM aims to provide guidelines and a methodological framework to quantify economic, social, operational, environmental, and regulatory aspects, in order to examine the feasibility of DC projects. The DCAM has been developed with an innovative approach to planning and designing DC projects, an approach that is both holistic and very practical.

A DC project can generate additional expenditures or it can generate savings. The DCAM enables the quantification of cost and benefit components for examining expenditures/savings related to DC for various alternatives and scenarios by comparing the situation before placing the composter (BPC) to the situation after placing the composter (APC)—a schematic illustration is presented in Figure 3. The DCAM provides a powerful tool for decision making based on a Benefit/Cost (B/C) index, and can be applied for a specific period or over time. The B/C index is a pseudo-cost–benefit ratio defined for assessing economic, social, operational, environmental, and regulatory viability, taking into account the various impact variables.

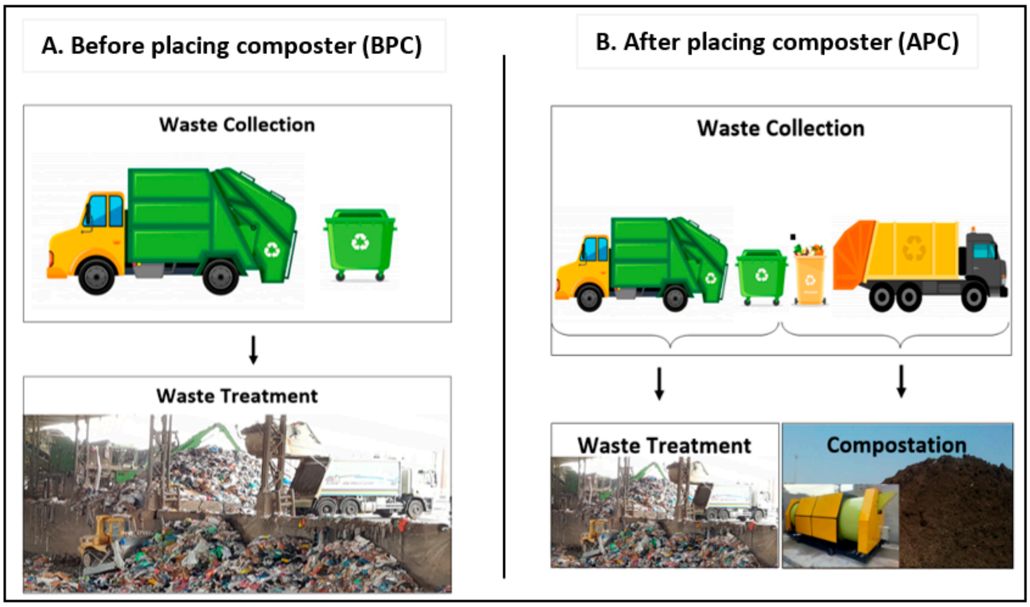

Figure 3. Schematic illustration of MSW collection and treatment BPC and APC.

In this paper, we describe the DCAM and its methodological framework, along with numerical examples to demonstrate its implementation. As such, we focus this paper on the quantitative analysis of DC.

3. Methodological Framework

The methodological framework is based on the model developed to examine the feasibility of DC, the decentralized composting analysis model (DCAM). The DCAM is based on the quantification of various characteristics of DC projects, and on performing a cost–benefit analysis to quantitatively assess the impact of these projects. A qualitative analysis is used as a complementary tool to support decision making in cases where the quantitative analysis is unequivocal. The paper does not aim to recommend a specific DC technology, nor to compare DC technologies, but presents a model for assessing the viability of such projects.

The suggested methodological framework can be implemented to address the short-term and/or long-term viability of DC projects by calculating the B/C indices for the different scenarios for a specific period or over time. The feasibility timeline can be assessed according to different criteria, alternatives, and pre-defined scenarios, and can serve as a decision-making support tool for planning the initial set-up of the project and its evolution over time.

The DCAM consists of several orderly stages, each of which uses a specific methodology to examine the feasibility of the project and its effectiveness. The DCAM provides methodological tools and guidelines for both quantitative and qualitative analyses to support decision making. In this paper, we focus on quantitative analysis. A schematic description of the DCAM stages is presented in Figure 4.

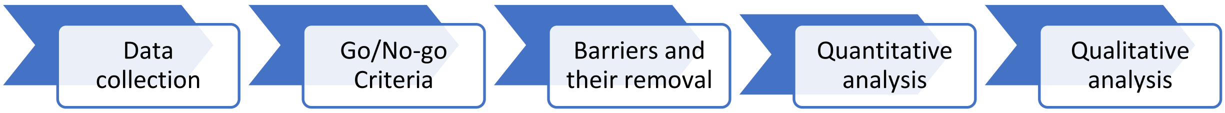

Figure 4. Schematic description of the DCAM stages.

3.1. Data Collection

A major challenge in DC planning and design is collecting and accessing relevant data to evaluate the impact of the project. MSW generation and management data, when available, are usually aggregated to the city, region, or state, while estimating the impact of DC projects requires data to be disaggregated to community or household levels [8].

The DCAM requires a variety of data, including specific data regarding the number and characteristics of participants in the DC project, to enable the quantification of the project's costs and benefits. This includes, for example, the amount of MSW generated by the participants, the percentage of OW in that stream, and the quality of the OW (e.g., from a typical household, supermarket, or restaurant). The DCAM takes into account various aspects, including economic, social, operational, and environmental elements, as well as the regulations in place. As detailed in the following sections, the DCAM defines the required data, and provides guidelines for its collection. Figure 5 shows the main categories of required input for the DCAM.

Figure 5. Main categories of required input for the DCAM.

3.1.1. Data on Project Characteristics

There are several categories associated with the DC project characteristics. Pai et al. [8] defined four such categories and their desired impact, as follows:

i. Operational characteristics—DC should drastically reduce the transportation requirements for waste processing and treatment. Additionally, the resultant product should be used onsite, or by members of the local community.
ii. Environmental characteristics—DC should enable the reuse of organic matter, with the compost providing a substitute for energy-intensive fertilizers, and it should engage the local community in the separation at source of food waste, which has been shown to reduce the generation of food waste.
iii. Economic characteristics—DC should reduce the collection, transportation, and treatment costs.
iv. Social characteristics—DC should stimulate local economies by creating local small-scale enterprises.

To collect the relevant data on the DC project characteristics, we have defined a set of questions, arranged as a questionnaire—see Appendix A.

3.1.2. Data on Regulation

Regulation has a profound impact on the implementation of MSWM [2,3,29]. Extended producer responsibility (EPR), waste collection fees, such as Pay as You Throw (PAYT), landfill tax and other regulatory tools, have a significant impact on the economic viability of the different MSWM solutions [1,2,17]. Thus, to examine the feasibility of DC projects, the analysis should entail quantifying the impact of the relevant regulation on the costs and benefits. Regulation may motivate or limit the implementation of various waste treatment solutions. For example, businesses that are required to pay a weight-based waste collection fee will strive to promote local solutions that reduce the amount of waste. Therefore, it is likely that businesses that produce large amounts of OW, such as restaurants, hotels, hospitals, etc., will collaborate with DC projects. Local authorities that pay the landfill levy will also strive to increase the amount of waste treated and decrease the amount of waste sent to the landfill, resulting in better cooperation with DC projects. Similarly, residents who pay according to the amount of waste they generate (PAYT) are more likely to collaborate over time with DC projects relative to residents who pay a flat rate. This emphasizes the need for quantification of the regulatory impact when examining the costs and benefits of the DC project. It is noted that this DCAM is a generic "cookbook"; therefore, each city/community wishing to adopt and implement DC can follow the guidelines using its own data.

Regulations that may be relevant to DC projects, along with examples, are presented in Table 1.

Table 1. Regulation that may be relevant to DC projects.

Regulatory Tool	Examples	Source
PAYT	USA: • In communities with pay-as-you-throw programs (also known as unit pricing or variable-rate pricing), residents are charged for the collection of municipal solid waste—ordinary household trash—based on the amount they throw away. This creates a direct economic incentive to recycle more, and generate less waste.	https://archive.epa.gov/wastes/conserve/tools/payt/web/html/index.html (accessed on 1 November 2022)

Table 1. *Cont.*

Regulatory Tool	Examples	Source

Separate collection at source	Greece:
	• The new national plan on waste management is oriented to the following targets:
	  ■ The reduction in the amount of waste being buried in landfills to below 10% by 2030.
	  ■ The implementation of separate collection for waste and bio-waste materials.
	• The separate collection of biological waste becomes mandatory as of 31 December 2022.
		https://kalaw.gr/waste-management-in-greece-under-the-current-legislative-framework/ (accessed on 1 November 2022)

Clear Targets regarding food waste (OW) and/or prohibition of landfilling of OW	EU/UN: • The current indicative EU-wide food waste reduction targets are 30% by 2025 and 50% by 2030, which align with SDG target 12.3.	https://www.euractiv.com/section/agriculture-food/news/eu-nations-set-to-define-new-era-of-food-waste-policy/ (accessed on 1 November 2022)
Landfill Levy	Israel: • Requires municipalities to pay a levy for every ton of MSW landfilled.	https://www.gov.il/en/departments/guides/landfilling_in_israel?chapterIndex=5 (accessed on 1 November 2022)
Composting registration/permits	USA: • Any small compost site that has more than 4 cubic yards of material on-site, at any time during the year, is required to register with the local authority.	https://www.compostingcouncil.org/page/StateRegulations (accessed on 1 November 2022)
Composting limitation/OW treatment capacity limitation	Italy: • Local composting: Not exceeding 80 t/y • Community composting: Not exceeding 130 t/y USA: • Backyard compost sites shall not exceed a total of four cubic yards in volume. The maximum height of the composting container shall be five (5) feet. See: Model Backyard and Small Composting Site Ordinance. • Small compost sites cannot exceed 120 cubic yards of material on-site at any time. See: Model Backyard and Small Composting Site Ordinance.	https://www.mdpi.com/2071-1050/12/8/3319 (accessed on 1 November 2022) https://www.compostingcouncil.org/page/StateRegulations (accessed on 1 November 2022)
Home composting limitations	Germany: • Space requirement for the utilization of compost produced in home composting (gardening space) should be at least 25 m^2, preferably above 50 m^2.	https://www.yumpu.com/de/document/read/12652580/biotonne-versus-eigenkompostierung-a-stand-und-perspektiven- (accessed on 1 November 2022)

Table 1. *Cont.*

Regulatory Tool	Examples	Source
Backyard compost site limitation	USA: • A site no greater than four cubic yards • Composting containers shall be located and designed so that seepage from the compost will not run off into public or private streets, storm sewers, drainage ditches, water retention basins, streams, or lakes. • No compost container may be located closer than five (5) feet to any rear or side property line, or closer than twenty (20) feet to any residential dwelling, except the dwelling on the property at which the compost container is located. • No compost container may be placed within twenty (20) feet of any body of water, or area designated as a 100-year flood plain or state-protected wetland.	www.mncompostingcouncil.org/uploads/1/5/6/0/15602762/model_composting_ordinance_-_5.2.15_-_for_5.5.event.docx (accessed on 1 November 2022)
Incentives, grants, and financial support (From the government, local authorities, and non-governmental organizations)	Spain: • Municipalities in Spain receive 60 € per composter per year from the government for community composting. Italy: • The Italian regulation provides tariff discounts for those who participate in community composting projects.	https://www.enicbcmed.eu/sircles-spain-meets-master-composter-better-understand-challenges-biowaste-management (accessed on 1 November 2022) https://www.mdpi.com/2071-1050/12/8/3319 (accessed on 1 November 2022)
A commercial waste collection fee	Israel: • Criteria for collecting basic waste and excess waste from businesses State of Connecticut, USA: • For commercial waste generators that generate a projected annual volume of 52 tons or more per year of source-separated organic material, AND are located within 20 miles of a permitted recycling facility, that material must comply with this law.	https://portal.ct.gov/DEEP/Waste-Management-and-Disposal/Organics-Recycling/Commercial-Organics-Recycling-Law (accessed on 1 November 2022) (in Hebrew)
Targets to reduce MSW landfill	Israel: • Regulations require local authorities to reduce their waste for disposal through recycling, under graduated recycling targets.	https://www.gov.il/en/departments/guides/landfilling_in_israel (accessed on 1 November 2022)
Targets to reduce organic waste landfill	EU: • The Landfill Directive (1999/31/EC) obliges the Member States to reduce the amount of biodegradable municipal waste that they send to landfill.	https://ec.europa.eu/environment/topics/waste-and-recycling/biodegradable-waste_en (accessed on 1 November 2022)

Table 1. *Cont.*

Regulatory Tool	Examples	Source
Location requirements for small compost sites	State of Minnesota, USA: • Composting containers shall be located and designed so that seepage from the compost will not run off into public or private streets, storm sewers, drainage ditches, water retention basins, streams, or lakes. • Small Compost Sites are allowed in (insert local zoning region codes [ex: C3, R2] areas, or in R1 areas as an accessory to a community garden or urban farm). Compost Sites may not be located closer than ten (10) feet to any rear or side property line, or closer than twenty (20) feet to any residential dwelling, except the dwelling on the property in which the compost pile is located. • No compost activities may be conducted within twenty (20) feet of any body of water, or area designated as floodplain, shoreland, or state-protected wetland, according to MN Rule 7035.2555.	https://www.revisor.mn.gov/rules/7035.2555/ (accessed on 1 November 2022) and www.mncompostingcouncil.org/resources-for-compost-sites.html (accessed on 1 November 2022)
Green Jobs allocation	Spain: • Master composter: qualified technicians who understand the composting process, and can analyze any problems that may arise in the process.	https://www.enicbcmed.eu/sircles-spain-meets-master-composter-better-understand-challenges-biowaste-management (accessed on 1 November 2022)

An example of the mapping of regulations in Israel is given in Appendix B.

3.1.3. Data on Costs and Benefits

To evaluate the costs and benefits of a DC project, the data should relate to the participants in the project only and reflect the change as a result of the DC project (i.e., before and after placing the composter) in order to be relevant. The data include the organic fraction or mixed waste, in case there is no waste separation at the source, before implementing the DC project. Other source-separated fractions (plastic, glass, etc.) that are not expected to change due to the DC project are irrelevant.

The participation rate is reflected in the amount of OW directed to composting, and thus can be quantified accordingly. The required data for benefit-cost analysis and the calculation of the B/C indices are as follows:

1. The total costs of waste collection, transportation and treatment, before placing the composter (BPC), and after placing the composter (APC).
2. The monthly amount of organic waste directed to composting BPC and APC (in some cases, the amount BPC is 0).

The DCAM includes detailed templates that are built for gathering the relevant data for calculating the costs and benefits—see Appendix C.

3.2. Go/No-Go Criteria

Go/No-go criteria are the necessary criteria for the DC project to exist (pass/fail criteria), and must all be met cumulatively. Thus, examining the Go/No-go criteria is the first step in the DCAM.

Four Go/No-go criteria are identified:

1. Suitable location—The first Go/No-go criterion is the existence of a suitable area for placing the composter. Locating a suitable area depends on the project characteristics, the land use designations, and various regulatory restrictions. To locate a suitable

area, it is advisable to work in cooperation with the local authority and the relevant regulatory bodies.

2. Willingness of participants—The second Go/No-go criterion is the willingness of the organic waste generators to participate in the DC project. For this purpose, suitable participants must be found and their consent to participate in the project must be obtained. These participants can be domestic or commercial waste producers. To find suitable participants, it is recommended to examine the regulations and their impact on potential participants, as well as the possible incentives, challenges, and limitations. However, without the willingness of participants, it is not possible to carry out the DC project.
3. Regulator approval—To place composters and carry out the DC project, it is necessary to meet various regulatory requirements and obtain the approval of the regulator, which is the third Go/No-go criterion. The regulators, and the regulations they enact, are crucial for setting areas aside for DC projects, for subsidizing such projects, for establishing incentives and regulatory tools to encourage DC.
4. Funding—The fourth Go/No-go criterion is funding. A DC project requires funding for the purchase of composters and their ongoing operation and maintenance; without such funding, the project cannot be carried out.

The four Go/No-go criteria that were identified are summarized in Table 2.

Table 2. Go/No-go Criteria.

Go/No-Go Criterion	Yes/No
Existence of a suitable area for placing the composter	
Participants' willingness to take part in the project	
Regulator's approval	
Funding for the project	

3.3. Barriers and Their Removal

Despite local and global efforts to produce a public perception of "turning waste from nuisance to resource", most of the public still treats waste as something that needs to be disposed of as quickly and remotely as possible. The literature describes different approaches and methods regarding how to increase public involvement in waste management, as well as assess the public's willingness to cooperate [30–39]. For a community composting project to be successful, it is strongly advisable to map out the barriers and explore ways to overcome them, motivate waste producers with incentives, and act to reduce objections.

Different countries and regions have different barriers, and thus, different ways to overcome them, along with the costs involved in those actions. For example, some challenges can be overcome through proper maintenance (to keep the composter area clean, prevent odour hazards, etc.), which has associated costs. Other costs, such as public information and awareness costs, personnel costs, costs of adequate facilities etc., should also be taken into account in the pricing of the project. Barriers that cannot be addressed quantitatively should be addressed qualitatively.

A common practical way to map barriers and ways to overcome them is to conduct an expert survey. The survey results can be analysed by various tools. A strategic tool that allows the mapping of major barriers and ways to remove them is the Strengths, Weaknesses, Opportunities, and Threats (SWOT) methodology [40–43].

The main barriers can be deduced from the Weaknesses and Threats, using the Focused Current Reality Tree (fCRT) methodology. The method involves taking the Weaknesses and Threats from the SWOT analysis, which are unwanted effects. The fCRT is then constructed by making logical connections between these unwanted phenomena, and identifying one (1) to three (3) strategic root problems, which are essentially the main barriers.

Similarly, ways to overcome barriers can be deduced from the Strengths and Opportunities, using the Core Competence Tree (CCT) methodology. The method is to take the Strengths and Opportunities from the SWOT analysis, which are desirable effects, to construct the CCT by making logical connections between these desirable phenomena, and identifying one (1) to three (3) strategic ways to overcome the barriers.

Daskal et al. [2] used this methodology to analyse barriers and ways to overcome them in the MSW market in Israel. A schematic description of the process is shown in Figure 6.

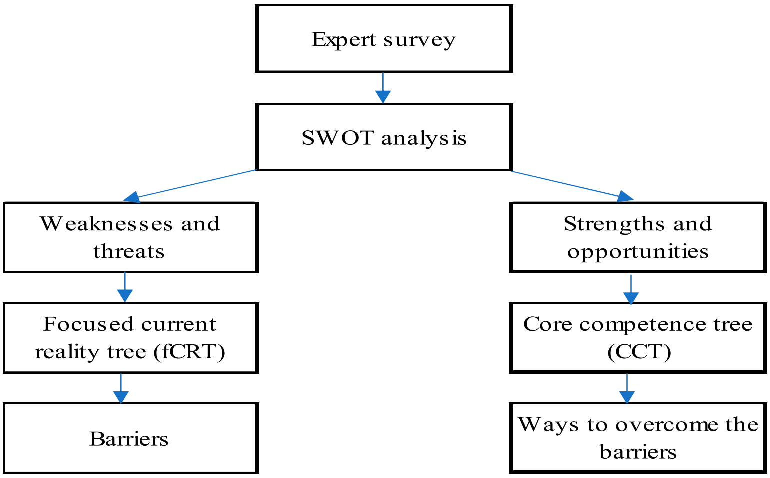

Figure 6. The framework for identifying barriers and ways to overcome them.

Table 3 below presents possible barriers and suggested ways to overcome them.

Table 3. Barriers and suggested ways to overcome them.

Barrier	Suggested Ways to Overcome It
NIMBY (Not In My Backyard)	• Initiating and managing public participation and awareness campaigns • Education and information programs
Quality of input material	• Awareness campaigns • Participant training • Continuous quality control • Enforcement under municipal by-laws and related charges
Odor management	• Assurance of proper compost mix • Adequate facilities such as moisture content control, fans, etc.
Animal/rodent hazards	• A completely closed composting system • External coating against rodents and other animals
Flies and insects	• Maintaining cleanliness

Table 3. *Cont.*

Barrier	Suggested Ways to Overcome It
Availability of bulking/pruning material	• Through the municipality (for example, tree waste) • Collaboration with relevant industries
Storage area for feedstock and compost	• A suitable infrastructure prepared in advance
Demand for compost (creating/increasing demand)	• Production of high-quality compost • Marketing and advertising • Making compost accessible to potential consumers
Availability of energy/water for the process	• Through the municipality
Maintaining/increasing the participation rate	• Reasonable and convenient distances from participants (households/businesses) • Enforcement under municipal by-laws and related charges

Source: Expert survey conducted by the authors (2021).

3.4. Quantitative Analysis

3.4.1. The Costs

In the MSW field, it is customary to have monthly payment arrangements with the various contractors. Accordingly, the cost components in the DCAM were also determined on a monthly basis. To evaluate the B/C index of a DC project, the total monthly costs should be evaluated before and after placing the composter, as follows:

I. The total actual monthly cost of the waste collection, transfer, and treatment, before placing the composter (BPC), and

II. The total estimated monthly cost of the waste collection, transfer, and treatment after placing the composter (APC).

The estimated monthly cost APC may be assessed according to various implementation options, including a long-term forecast for assessing feasibility according to the expected participation rate, and/or other criteria.

Various cost components that may be relevant to the cost analysis of the DC project are shown in Table 4, sorted into social, operational, environmental, and regulatory categories. Various alternatives and scenarios are presented in Section 3.4.4.

Table 4. Key cost components.

Category	Key Cost Components
Social	• Educational activities • Publicity • Supervision • Enforcement
Operational	• Waste collection • Waste treatment/gate fee • Maintenance

Table 4. *Cont.*

Category	Key Cost Components
Environmental	• Emissions prevention • Odor prevention
Regulatory	• PAYT • Business waste collection fee • Landfill tax

3.4.2. The Benefits

The benefits of DC projects derive from the treatment of OW through composting. This is reflected by the reduction of collection, transportation, and treatment costs, and embodies environmental benefits such as reduced transportation operations and decreased landfilling. Thus, the quantification of the benefits is directly based on the amount of organic waste directed to composting. The total monthly benefit should be evaluated before and after placing the composter using the following:

I. The actual monthly OW amount directed to composting BPC (if it exists), and
II. The estimated monthly OW amount directed to composting APC.

The amount of OW directed to composting can also indicate the growth in participation rate, for a specific area with a fixed number of participants. When the amount directed to composting APC increases, it is likely the result of an increased participation rate in that specific area. Therefore, the amount of OW directed to composting is an indicator of the feasibility of the DC project at different participation rates, both for a specific period and over time.

3.4.3. The Benefit/Cost Index

The B/C index is a pseudo-cost-benefit ratio defined for assessing the DC project viability, taking into account the various impact variables. The B/C index allows a comparison between different alternatives and scenarios by measuring the cost/benefit ratio for each of them before and after placing the composter. The cost refers to the total monthly expenditure or savings for waste collection, transportation, and treatment. The benefit refers to the monthly amount of organic waste directed to composting. We refer to the cost in Euros and the benefit in tons.

Table 5 presents the methodology for calculating the B/C indices and Table 6 presents a numerical example for calculating benefit/cost indices.

Table 5. The benefit/cost index calculation.

	BPC	APC
Cost (Euro)	X1	X2
Benefit (ton)	Y1	Y2
B/C calculation	Y1/X1	Y2/X2
B/C index	In.1 = value(Y1/X1)	In.2 = value(Y2/X2)

Table 6. Example for calculating benefit/cost indices.

	BPC	APC—Option 1	APC—Option 2
Cost (Euro)	120,000	90,000	80,000
Benefit (ton)	0	60	85
B/C calculation	0/80	60/90,000	85/80,000
B/C index	In.BPC = 0	In.APC1 = 0.0006	In.APC2 = 0.0010

Following in Table 6 is a synthetic example of calculating the B/C indices using the methodology in Table 5. The two APC options differ in the type of composter, which is reflected in the cost and amount of organic waste treated.

Since In.APC2 > In.APC1 > In.BPC, the calculations show that APC Option 2 is the most effective of the three options.

The model can be implemented for comparing different options that reflect various alternatives and scenarios. These may include taking into account budget constraints, different technological solutions, different collection methods, transportation alternatives, implementing different regulatory tools, examining different scenarios of participation rates, and more.

3.4.4. Comparison between Different Alternatives and Scenarios

The Benefit/Cost index is a practical and effective tool for comparing different alternatives and scenarios. The comparison conclusions are made according to the index calculations for each option, as demonstrated in Section 3.4.3.

The efficiency of the DC project can be evaluated according to different characteristics, alternatives, and scenarios, which include, but are not limited to, the following:

- Countries
- Cities/regions
- Composters/technological solutions
- Numbers of participants
- Participation rates (at a specific time and/or over time)
- Amounts of organic waste
- Operation and maintenance procedures
- Home, community, or commercial composting (or combinations thereof)
- Waste collection methods
- Waste collection frequencies
- Transportation alternatives
- Regulatory tools

3.5. Qualitative Analysis

Qualitative analysis is a complementary tool to support decision making in cases where quantitative analysis is unequivocal. The DCAM qualitative analysis involves obtaining information from experts in the field and analysing that information to identify root problems, as well as the ways and means to solve these problems. To locate the main "players" relevant to the project, the start is the identification and mapping of stakeholders, followed by the construction of the market arena. Next, information is obtained from these stakeholders and is used to perform a SWOT analysis as the final step. To collect and process the information, a methodology has been defined that allows the classification of desirable and undesirable phenomena. This paper focuses on the methodological framework of quantitative analysis.

3.6. Summary

In this section, we have presented the DCAM and how to apply the methodologies in each step. A schematic description of the DCAM framework is presented in Figure 7.

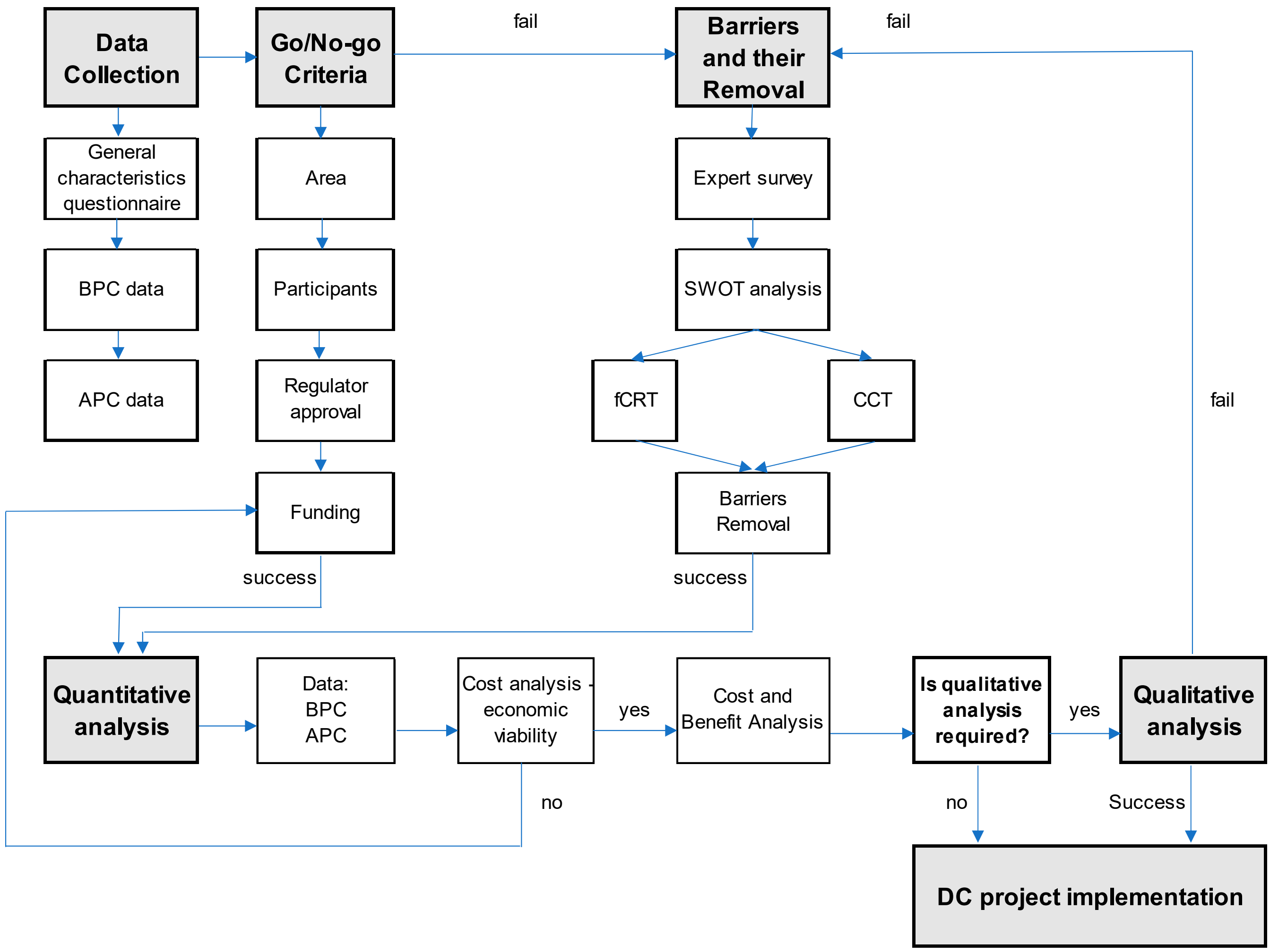

Figure 7. Schematic description of the DCAM framework.

The DCAM has been implemented in Spain, Italy, Israel, Jordan, and Palestine, as part of the 'Decentralised Composting in Small Towns' (DECOST) project [44]. As part of the implementation, various alternatives were compared, including sensitivity tests. Although the model has not yet been implemented in large cities, it can be easily implemented in any country, region, city, or area.

Following are the results for the city of Shefar'am in Israel in Section 4, the discussion in Section 5, and the conclusions in Section 6.

4. Results for the City of Shefar'am in Israel

The following are the results of the DC analysis for the city of Shefar'am in Israel, using the DCAM. Three DC options were analysed and compared to determine the most viable option for Shefar'am, with the options being commercial composting, community composting and home composting.

4.1. The City of Shefar'am

Shefar'am is an Arab city in the northern district of Israel, located at the entrance to the Galilee region. In 2019, Shefar'am had a population of about 42 thousand residents [45]. Approximately 32,000 tons of waste are produced in Shefar'am each year, of which 18,000 tons are classified, according to municipal records, as mixed household waste. This includes the waste collected from businesses located in the heart of the city and the residential neighbourhoods [18]. The DCAM was generated for three (3) options: commercial composting, community composting and home composting.

4.2. Commercial Composting

The main characteristics of the DC project for the composting of commercial OW are described below.

- General project characteristics
  - Country: Israel
  - City: Shefar'am
  - Type of MSW: Commercial
  - Participants: 15 Greengrocers
- Regulation
  - Landfill tax of EUR 32.40 per ton
  - There is no direct waste collection fee for businesses
- Collection and treatment BPC
  - 15 × 1100-Litre plastic bins (one per greengrocer)
  - Mixed waste
  - 2/3 of the mixed waste is organic waste
  - Total amount of waste ~4.5 tons per day (~300 kg per greengrocer)
  - Total cost per ton— EUR 153.50 (including 17% VAT)
- Collection and treatment APC
  - Composter type and model: HotRot 1811
  - Waste collection
    - 1100-Litre bins for OW
    - 360-Litre bins for residual waste

The monthly cost and benefit for Shefar'am's commercial composting are presented in Table 7.

Table 7. Commercial composting cost and benefit results for Shefar'am.

	BPC	APC
Cost (Euro)	15,349	11,498
Benefit (ton)	7.8	78.00
B/C index	0.0005	0.0067

Since In.APC > In.BPC, the calculations show that option APC is more viable than option BPC; thus, commercial composting is worthwhile.

4.3. Community Composting

The main characteristics of the DC project for community composting of domestic OW are described below.

- General Project characteristics
  - Country: Israel
  - City: Shefar'am
  - Type of MSW: Domestic
  - Participants
    - Population—731
    - No. of apartments—180
- Regulation
  - Landfill tax of EUR 32.40 per ton
  - There is no direct waste collection fee
- Collection and treatment BPC
  - 360 and 1100-Litre plastic bins

- ○ Mixed waste
- ○ Total cost per ton—EUR 153.50 (including 17% VAT)
- Collection and treatment APC
  - ○ Composter type and model: CtTec—Bio—Bi I.3.X—4 composters
  - ○ 360-Litre bins for OW and residual waste

The cost and benefit results are presented in Table 8.

Table 8. Community composting cost and benefit results for Shefar'am.

	BPC	APC
Cost (Euro)	9278	10,193
Benefit (ton)	6.1	14.4
B/C index	0.0006	0.0014

Since In.APC > In.BPC, the calculations show that option APC is more viable than option BPC, thus community composting is worthwhile.

4.4. Home Composting

The main characteristics of the DC project for home composting of domestic OW are described below.

- General Project characteristics
  - ○ Country: Israel
  - ○ City: Shefar'am
  - ○ Type of MSW: Domestic
  - ○ Participants:
    - ■ Population—731
    - ■ No. of apartments—180
- Regulation
  - ○ Landfill tax of EUR 32.40 per ton
  - ○ There is no direct waste collection fee.
- Collection and treatment BPC
  - ○ 360 and 1100-Litre plastic bins
  - ○ Mixed waste
  - ○ Total cost per ton—EUR 153.50 (including 17% VAT)
- Collection and treatment APC
  - ○ 180 home composters
  - ○ 360-Litre bins for residual waste

The cost and benefit results are presented in Table 9.

Table 9. Home composting cost and benefit results for Shefar'am.

	BPC	APC
Cost (Euro)	9278	8076
Benefit (ton)	6.1	15.7
B/C index	0.0006	0.0019

Since In.APC > In.BPC, the calculations show that option APC is more viable than option BPC, thus home composting is worthwhile.

4.5. Comparison

In comparing the three examined DC options for Shefar'am, relevant conclusions can be made when rating the options based on their respective B/C indices. A summary of the calculated results is presented in Table 10.

Table 10. Summary of the results of the three DC options for Shefar'am.

	APC Option 1 Commercial Composting	APC Option 2 Community Composting	APC Option 3 Home Composting
COST (EURO)	11,498	10,193	8076
BENEFIT (TONS)	78.0	14.4	15.7
B/C INDEX	In.1 = 0.0067	In.2 = 0.0014	In.3 = 0.0019

The results show that the best option is commercial composting, with the highest B/C index of 0.0067 (In.1 > In.3 > In.2). As for community composting vs. home composting, results show that the index for home composting (0.0019) is higher than the index for community composting (0.0014); thus, home composting is preferable to community composting. That said, other qualitative factors, not discussed in this paper, must be taken into account, for example, the ability to reach participants for home composting, maintaining a high participation rate over time, and more.

5. Discussion

OW management solutions should be analysed in an integrative manner by considering economic, social, operational, environmental, and regulatory aspects [1,2,17,25–28]. The DCAM provides a unique and innovative methodological framework along with detailed guidelines for examining the feasibility of DC projects, taking into account these aspects. The model provides methodological tools for both quantitative and qualitative analyses that result in B/C indices to support decision making. The B/C index methodology allows the comparison between different alternatives and scenarios. The index is based on universal values—monetary costs and the amount of waste in tons—so it allows comparison across countries, regions, time periods, and so on. To facilitate the use of the model by various parties, such as regulators and local authorities, a specific questionnaire and templates were developed for the collection and analysis of the relevant data.

Beyond performing the analyses, trust between the local authority and the residents is a crucial factor in the success of DC projects [30–39]. It is recommended, therefore, to conduct a satisfaction survey as a preliminary step before the DC project implementation. As there is sometimes a gap between the authority's perception of the residents' trust and the actual situation, it is recommended that the satisfaction survey be performed by an external party/consultant to prevent bias.

6. Conclusions

A prominent approach for treating organic waste is decentralized composting (DC). Despite its relevance, the existing research does not address, for the most part, the various aspects involved with DC projects.

Examining the viability of DC is critical as it involves financial investment and building trust with the public. The DCAM allows the feasibility analysis of DC projects through quantitative and qualitative analyses. The model takes into account economic, social, operational, environmental, and regulatory aspects. The methodology is generic and offers tools based on universal values; thus, it allows comparison between different countries, regions, municipal authorities, time periods, and scenarios. As such, this unique and innovative model provides a powerful tool for decision makers to pre-evaluate DC projects, rather than making a comparison based on different scenarios only, or post-evaluate them after they have already been implemented.

In the present study, the benefit was defined as the amount of organic waste treated. Future research can expand this definition to include the usage of compost, urban agriculture, reduction in greenhouse gas emissions, and more.

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Acronyms

APC	after placing composter
BPC	before placing composter
B/C	benefit/cost
CCT	core competence tree
DC	decentralized composting
DCAM	decentralized composting analysis model
DECOST	Decentralised Composting in Small Towns
EPR	extended producer responsibility
fCRT	focused current reality tree
MSW	municipal solid waste
MSWM	municipal solid wate management
OECD	Organisation for Economic Co-operation and Development
OW	organic waste
PAYT	pay as you throw
SWOT	strengths, weaknesses, opportunities, and threats

Appendix A. The DCAM General Characteristics Questionnaire

These questions relate to the participants in the DC project and the characteristics of the potential project site.

1. Country/State: _____________
2. Region/City/Town: _____________
3. Name of Neighborhood (if applicable): ___________________
4. Area characteristics: Residential (neighborhood)/Commercial/Industrial/Other: ______
5. Size of the area in square meters: ___________ m^2
6. National socio-economic status: High/Medium/Low/Other: ______________
7. Household waste: Yes/No
8. Commercial waste: Yes/No
9. No. of businesses: _____
10. No. of households: _____
11. Average number of persons per household: ___________

12. No. of high-rise buildings: _____/______% of total participants
13. No. of single homes: _____/______% of total participants
14. Mode of waste management payment by households: within general municipal taxes/any mode of Pay as You Throw/Other: ________________
15. Mode of waste management payment by businesses: in general municipal taxes/any mode of Pay as You Throw/Other: ________________
16. Waste collection payment method: per bin or container hauling/per ton/Other: _____
17. Waste treatment payment method: tipping fee per ton/Other: ___________
18. Landfill levy: Yes/No
19. No. of composters in the project: ________________
20. Composter location: Coupled with each household/Community composter in public areas/Other: __
21. Allocated area for each composter: _______ m^2
22. Operational responsibility for the OW transportation: Residents/Businesses/Local authority/Other: _______
23. Operational responsibility for composting: Residents/Businesses/Local authority/Other: _______
24. Means of collecting the organic waste: bins/plastic bags/paper bags/bio-plastic bags/other: ___
25. Monthly amount of organic waste directed to composting: _____ tons
26. Composter type: _____________

Appendix B. Analysis of Waste and Recycling Legislation in Israel, 1984–2017

This table is an example of legislation mapping in Israel and identifying the relevant regulations for a DC project.

Relevance to DC	Source	Purpose	Legislation	Year
-	[46]	"Prohibits littering or the disposal of waste, building debris, and vehicle scrap in the public domain."	Maintenance of Cleanliness Law	1984
+	[47]	"Provides the principles and the legal framework for recycling in Israel. It authorizes local authorities and obliges them, when required by the Minister of Environmental Protection, to allocate sites for recycling centres and to install recycling facilities and containers".	Collection and Disposal of Waste for Recycling Law	1993
+	[48]	"These regulations require local authorities to reduce their waste for disposal through recycling, under graduated recycling targets as per the following timetable: at least 10% by December 1998; 15% by December 2000; 25% by December 2007".	The Obligation of Waste Disposal for Recycling Regulations	1998
-	[49]	"Required manufacturers, importers, and retailers to collect a deposit on beverage containers larger than 0.1 Litres and smaller than 1.5 Litres, except for bags or paper containers. A recycling corporation was established under the law to institute a refund, bottle collection, and recycling system, which was required to comply with graduated targets for collecting empty beverage containers".	Deposit on Beverage Containers Law	1999

Relevance to DC	Source	Purpose	Legislation	Year
+	[50]	"In effect since 1 July 2007; requires landfill operators to pay a levy for every ton of waste landfilled. The aim is to internalize the full and real costs of waste treatment and disposal".	Amendment to Maintenance of Cleanliness Law, 2007: Landfill Levy	2007
-	[51]	"Aims to reduce the environmental nuisance caused by improper tire disposal in Israel, while promoting tire recycling. The law makes tire producers and importers responsible for the disposal and recycling of used tires at graduated rates each year, with recycling replacing disposal after July 2013".	Tire Disposal and Recycling Law	2007
-	[52]	"This law imposes direct responsibility on manufacturers and importers in Israel to collect and recycle the packaging waste of their products".	Packaging Law	2011
-	[53]	"This law establishes measures regarding the environmental treatment of electrical and electronic equipment and of batteries and accumulators, to encourage the reuse of electrical and electronic equipment, reduce the quantity of waste created from electrical and electronic equipment and from batteries and accumulators, prevent the burial of such waste, and mitigate the negative environmental and health effects of electrical and electronic equipment, of batteries and accumulators, and of the waste from these products".	Electrical and Electronic Equipment and Batteries Law	2012
-	[54]	"Reducing the use of carrying bags to reduce the amount of waste generated by their use and the negative environmental effects of this waste, inter alia by restricting the distribution of disposable bags by dealers without payment and by imposing a duty to sell them".	The Law for the Reduction of the Use of Disposable Carrying Bags	2016
+	[55]	Imposes an obligation on local authorities to collect basic waste from businesses, and imposes a waste collection fee on businesses for the collection of excess waste.	It is mandatory to enact a municipal bylaw defining the criteria for collecting basic waste and excess waste from businesses	2017

+ Applicable (Quantitative/Qualitative); - Not Applicable; Source: Daskal (2018) [56].

Appendix C. The DCAM Templates for Gathering Data for Cost and Benefit Calculations

Waste Properties
Source of the waste: Domestic/Commercial/Industrial
Type of waste: Mixed/Organic */Packaging */Other

* separated at source.

Waste Collection Data
Type of receptacle: can/bin/container/underground container
Volume (Litres)
No. of waste collection bins (WCB)

Weekly collection frequency
Total no. of monthly collections
The cost of one-time collection from one receptacle
Total monthly cost
Waste hauler (private/municipal)
The payer: local authority/business/resident

Waste Treatment Data
Name of the site that receives the waste
Distance of the site from the local authority/area of the project
Tipping fee to the waste site
Levy/tax
Cost per ton
Total Monthly amount (ton)
Total cost (according to total tons)

Fees/Other Related Payments
Fill this part in cases where the local authority bears the cost of waste collection and treatment, but charges a direct fee/payment (businesses/PAYT/other)
Service provider: local authority/contractor
Name of the local authority/contractor
A fee is charged for service by the local authority (Yes/No)
Fee per Ton

Composter & Composting Data—General Properties
Composter provider
Composter type and model
Capacity (tons per month)
Composter Dimensions
Volume
Area size required for placing the composter
Property rights on the land
Lifetime (Years/months)

Composter & Composting Data—Investment Cost
Cost of purchasing the composter
Site development and construction cost
Biofilter cost
Total monthly cost

Composter & Composting Data—Operation and Maintenance
Composter operation and maintenance cost
OW transportation cost
OW Loading cost
Cost of application/s for access & control
Biofilter cost

Benefit
Monthly Amount of OW Directed to Composting (Tons)

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