MUNICIPAL SOLID WASTE COST CALCULATION TECHNICAL GUIDELINES

For low- and middle-income countries

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Purpose and audience

Municipal Solid Waste Cost Calculation Technical Guidelines discusses good practices for calculating investment and operating costs in the solid waste management sector illustrated through notional cost calculations for waste management functions and a combined waste management system.

The report emphasizes the need to accurately determine the full costs of municipal waste services to establish recurrent financing needs and plan new investments. The publication aims to impress that funding annual operating expenses—typically higher than the annualized capital costs of investments and the single most important factor for sustaining waste operations—needs to be a key area of attention for local authorities. It emphasizes that the waste management sector is principally a net cost activity that requires financing; while investments in advanced treatment facilities and processes bring higher environmental and economic benefits, they also incur higher financial costs and hence revenue requirements.

The publication aims to support the work of technical departments within municipalities that inform, advise, and guide their municipal councils and policy makers. The guidelines were developed with consideration of the state of the sector and its development trajectory in low- and middle-income countries.

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This publication was developed under the general guidance of Bernice K. Van Bronkhorst, Global Director of the Urban, Land and Resilience Global Practice.

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Abbreviations

AD	Anaerobic Digestion
AIC	Average Incremental Cost
ASP	Aerated Static Pile
BSF	Black Soldier Fly
CA	Catchment Area
CEA	Cost-Effectiveness Analysis
CHP	Combined Heat and Power
CLO	Compost-Like Output
COD	Chemical Oxygen Demand
DCF	Discounted Cash Flow
DUC	Discounted Unit Cost (equivalent to AIC)
EPR	Extended Producer Responsibility
EU	European Union
HIC	High-Income Country
IVC	In-Vessel Composting
KPI	Key Performance Indicator
LIC	Low-Income Country
MBT	Mechanical Biological Treatment
MRF	Material Recovery Facility
MIC	Middle-Income Country
NIR	Near-Infrared Technique
O&M	Operation and Maintenance
PE	Polyethylene
PET	Polyethylene Terephthalate
PTO	Power Take-Off
PV	Present Value
R&D	Research and Development
RDF	Refuse-Derived Fuel
ROI	Return on Investment
SWM	Solid Waste Management
TA	Traditional Accounting
VAT	Value Added Tax
WEEE	Waste from Electrical and Electronic Equipment
WtE	Waste to Energy

The cost calculations provided in these guidelines are illustrative. The presented unit and overall costs are calculated for the assumptions made and based on assumed, specific parameters as provided. Listed costs should therefore be interpreted in their own context and must not be regarded as overarching or applicable across geographies or income groups.

Executive summary

Municipal Solid Waste Cost Calculation Technical Guidelines discusses good practices for calculating investment and operating costs in the solid waste management (SWM) sector. The document includes illustrative examples of notional cost calculations for selected waste management functions and for a combined waste management system.

The guidelines—using a step-by-step approach and set input data—demonstrate how the costs of each of the main municipal waste management functions are calculated and how changes in operational and/or technical requirements affect cost levels. They then show how the outputs from the initial cost analysis are combined to establish the total investment and operating costs of a notional waste management system. These are then used to determine indicative annual revenue requirements and full cost recovery tariffs. Outcomes from the analysis can also be used to answer several questions: are the proposed services affordable to users and municipalities; are they financially viable; is external grant funding needed; does the scope and scale of the envisaged system need to be re-examined?

The publication aims to impress that funding annual operating expenses—typically higher than the annualized capital costs of investments and the single most important factor for sustaining waste operations—needs to be a key area of attention for local authorities. It emphasizes that the waste management sector is principally a net cost activity that requires financing; while investments in advanced treatment facilities and processes bring higher environmental and economic benefits, they also incur higher financial costs and hence revenue requirements.

The document was prepared in response to interest expressed by many municipalities across geographic regions in receiving guidance to determine their operating costs from local unit rates. The publication aims to demonstrate the approach of establishing costs and support the work of technical departments within municipalities that inform, advise, and guide their municipal councils and policy makers in planning their waste systems, justifying and setting tariffs, and mobilizing finance. It is expected to assist municipalities in operating current systems more efficiently and improving municipal capacity to plan system improvements and expansions beyond current levels. The guidelines were developed with consideration of the state of the sector and its development trajectory in low- and middle-income countries (LICs and MICs).

The document is organized into seven chapters. The first chapter explains why it is important that municipal waste management departments know the full cost of their municipal waste services along the various functional components of the waste system. The second chapter presents the basic parameters and steps toward calculating system costs. The third chapter gives the notional cost calculations for selected waste management functions of municipalities of various sizes along with varying technical and organizational system alternatives (scenarios). The fourth chapter presents the notional costs of an entire combined waste management system under regional arrangements. The fifth chapter describes financial techniques used to evaluate technical options in terms of their cost implications and introduces the concept of *absolute* and *relative* costs for the various functions of the waste management system. The sixth chapter outlines approaches to calculate residential waste management tariffs. The final chapter discusses potential revenue from sale of separately collected and sorted materials and emphasizes that the waste management sector is principally a net cost activity.

Current and future service costs

Many municipal SWM departments in LICs and MICs are unaware of the full costs of their services. Rarely are costs allocated against specific service functions, such as waste collection or landfill operations, and many are recorded on a line-item basis with related services, such as drain cleaning, street sweeping and repairs, and snow removal. Separate financial and accounting records are not kept, and costs when needed—for example, to prepare a budget—are based on rough estimates at best. Costs often reflect predetermined norms for waste generation, unit input costs, and tariffs. They are rarely based on real, current, empirical data taken from recent experience or market prices. Problems with cost accounting also arise because waste service costs are often combined and brought under general budget items or, the opposite, spread across a range of budget items.

Chapter 1 outlines why it is important that municipal waste management departments know the full costs of their municipal waste services and the various functional components of the waste system. Before a municipality can define its actual financing needs, it must clearly define the full costs of its current services; only then it can establish the incremental costs of planned new investments and operations.

Although the largest single expenditure incurred in providing municipal waste services is typically for infrastructure investments, the most significant financial challenge usually is to estimate the annual revenue requirement and determine how it should be funded. Annual operational expenditures (excluding depreciation) are often higher than the annualized capital costs of investments, with estimates showing them to account for 70 percent or more of total annual budgetary requirements. It is therefore critical that the operational finance implication is fully considered when deciding on new capital expenses.

The financial costs of providing municipal solid waste services must be funded one way or another. Users must ultimately pay for the services they use, either directly though user charges or indirectly through municipal transfers/taxes or a combination of the two. Municipal waste services should be appropriate, affordable, socially acceptable, and financially sustainable. This means that municipalities should be clear about the scope of the services being provided, the full costs of those services, and how those costs—both investment and operational—are to be funded. This information enables realistic decisions to be made on whether the services proposed can be operated and funded sustainably over time.

It can be hard to secure financing for waste services if the full costs of service are not known—the single most important factor in sustaining operations. The municipal and higher-level authorities that typically approve financing for municipal waste management departments are more likely to approve requests to raise budget allocations and tariffs when they are supported by a full cost analysis. When requests are not supported in this way, budgets are likely to be assigned according to prior funding allocations and available municipal resources, which can lead to severe underfunding.

Without knowing the full costs of baseline services, it is also hard to plan system improvements. A current example is that of municipalities looking to introduce systems of waste separation at source in parallel with existing mixed waste collection and disposal systems. In the absence of a functional extended producer responsibility (EPR) scheme to finance the incremental costs, which is overwhelmingly the case in LICs and MICs, reliable data on the full cost of the existing mixed waste system should be the benchmark against which the incremental net costs of separation at source can be evaluated.

Once full costs are known, the annual revenue required to cover these costs can be established and indicative user tariffs estimated, for example, average cost per person or household. This does not mean that a full cost recovery charging system will be introduced but it does provide a powerful indicator of what the tariffs would need to be if a full cost recovery policy were to be introduced. If a partial user-based cost recovery system is proposed, for example, to cover operational or fixed costs only, the full cost analysis will help determine the balance of the municipal funds needed to cover the annual revenue requirement and for the services to be operated on a commercially sustainable basis.

Defining the waste management system

The waste management costs are a function of the adopted technical and organizational solutions to achieve the waste management objectives in the planning area.

Developing cost estimates is preceded by defining the planning area with its physical characteristics, preparing population forecasts and projections of waste quantities and composition, defining the waste management objectives, and formulating technical scenarios for the different elements of the system that allow the achievement of these objectives. Each of these has a significant impact on waste management costs.

Reliable data about the waste quantities generated are the basis for development of reliable waste projections. However, the available information is often limited to waste quantities collected and disposed of through the system managed by the local authorities. The estimates of generated waste quantities should consider all different sources and possible collection channels, including, for example, the recyclable waste collected by informal collectors, green waste collected from public areas, and illegally disposed waste. The impact of future waste prevention measures should also be considered.

Chapter 2 lists the physical parameters that determine current costs and possible technical alternatives to be considered when formulating different scenarios to achieve future waste management objectives. It then outlines the approach followed in subsequent chapters. First, it lists the individual waste management functions or principal components of the waste system included in the cost analysis in Chapter 3 which include collection of residual/mixed waste, municipal waste transfer, landfilling of waste, separate collection and sorting of recyclable materials, home composting, separate collection and composting of green waste, separate collection and treatment of food waste, and sorting and mechanical biological treatment (MBT) of residual waste.[1] Second, it lists the size of municipalities used for the subsequent examples of cost calculations—five service areas[2] with populations of, respectively, 10,000 residents, 50,000 residents, 100,000 residents, 250,000 residents, and 1,000,000 residents have been considered. These service areas, described in Chapter 4, are considered jointly as a single regional system with a population of 1.4 million residents.

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[1] Waste-to-energy (WtE) incineration is outside the scope of these guidelines.

[2] Also referred to as 'catchment areas' (CAs) or 'municipalities'.

Costing the principal components of the waste management system

Costs for the principal components of the waste management system could vary significantly based on input data, such as planning area size, scale, distances, technology, and many others.

Chapter 3 presents detailed cost calculations and estimates for each principal component of the municipal waste management system, that is, collection of municipal mixed waste, waste transfer, and so on, as outlined in the previous chapter. Descriptions of each component are given, together with scenarios for illustrating important considerations such as the economy of scale effect on the total and unit costs of the alternatives considered.

It is to be noted that the provided cost estimates for the different waste management operations should be interpreted with caution as they refer to the specific examples presented and based on assumptions and unit costs used in these guidelines. If applied to specific local conditions, significant deviations from the presented cost estimates can be observed due to the differences in waste quantities and composition as well as local and regional differences in the costs of labor, fuel, energy, construction, and materials. Major price differences are also observed between different manufacturers of equipment and vehicles, and costs for machinery with comparable technical characteristics can vary significantly. Local legal requirements, norms for emissions discharged into the environment, specific design and construction requirements, labor safety, and fire protection standards could also have a significant impact on the applied technical solutions and the related construction and equipment costs.

Municipal mixed waste collection

The chapter provides examples of cost calculations for mixed waste collection in a municipality with 100,000 residents, with 70 percent living in urban areas and 30 percent in rural areas. It then examines the impact on costs of different types and size of container systems, varying distance to treatment/disposal, loading times, collection frequency, vehicle size, and number of working shifts.

The examples provided are for illustrative purposes only. The actual collection systems in large agglomerations usually combine different collection schemes and logistic arrangements. Significant price differences could also occur as a result of social and cultural aspects that play a role in waste management system design.

The chapter lists the frequently observed mistakes when planning collection systems with bearing on costs and argues that low initial investment costs do not necessarily result in lowest overall costs over the implementation period. It provides important benchmarks on cost ranges per tonne of waste collected and a list of suggestions to optimize collection costs.

The cost for mixed municipal waste collection and transportation is estimated to be typically below $50/tonne[3] of waste and higher amounts may suggest a possibility for cost optimization. If, on the other hand, costs are below $20/tonne of waste, it should be checked that all cost components have been considered.

Municipal waste transfer

Transfer stations are often constructed with the expectation that they will reduce transportation costs.

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[3] All instances of $ in the document refer to US dollars.

The decision to construct a transfer station should be based on an options analysis. The economic expediency of transfer stations is influenced by factors such as distances, quantities of waste, road conditions and topography, density of population in the service areas, and technology of transfer.

Transportation distances, waste quantities collected, and residents served are typically the main factors to consider. As a general rule, transfer stations are usually not considered for transportation distances below 40 km and less than 50,000 residents served.

The chapter provides different alternatives for organizing municipal waste collection and transfer in a settlement with 100,000 residents, assuming average transportation distance of 50 km to treatment/disposal site. The main technical characteristics and costs for direct transportation of waste and using transfer station with and without compaction are provided and compared. An example of cost estimates for a transfer station serving 1,000,000 residents is also presented.

The cost of municipal transfer should typically be lower than municipal waste collection costs and could usually be expected in the range of \$8–\$20/tonne of waste transferred.

Municipal waste landfill

Landfilling of waste will continue to be a main disposal method in LICs and MICs even as other types of treatment increase.

Very often in LICs and MICs, insufficient funding is provided for operation and maintenance (O&M) of disposal sites. Landfill operations procedures are not strictly followed, resulting in low compaction rates, excessive leachate generation, steep slopes compromising stability, and so forth. As a result, the lifetime of the landfill site is reduced and higher costs per tonne of waste received are incurred than initially planned.

Another important factor affecting costs is waste quantities accepted on site. In case the site receives much less quantities than initially planned, considerably higher costs per tonne than initially estimated are incurred due to fixed investment and operating costs. On the contrary, if the landfill receives much larger quantities than planned, the capacity is utilized faster and the overall lifetime of the facility is reduced.

Typically, landfills are constructed in stages and the investment costs for constructing landfill cells appear over the whole life of the site. Costs for closure and aftercare related to monitoring of environmental parameters should also be considered during the lifetime of the facility.

Landfill costs demonstrate significant economies of scale. Large-capacity landfills allow higher average deposition height and more waste to be deposited per unit area occupied. This is demonstrated in the chapter through several examples of cost estimates for landfills of different sizes corresponding to the five sample municipalities (service or catchment areas) defined in Chapter 2.

The typical landfill costs for municipal waste are estimated to be in the range of \$12–\$30/tonne of deposited waste, assuming full cost recovery. Higher unit costs are possible if the landfill has relatively small capacity that in principle should be avoided.

Separate collection of recyclable waste

The separate collection of municipal waste is most often focused on paper, cardboard, plastics, metal, and glass. Other waste fractions such as textile and electronic waste can also be collected for recycling.

The quality of the collected materials is an important aspect for a successful recycling system. Both the demand and the value of recycled materials are directly linked to the way these materials were initially collected.[4]

The chapter described typically observed shortcomings when municipalities plan to introduce separate collection systems, for instance, overoptimistic projections of the recycling potential of the waste and/or unrealistic expectations for households' participation and source separation rates. The potential impact of informal sector collection is also often not considered. In case of significant presence of informal waste pickers, the most valuable waste fractions will be removed before entering the collection system or from installed collection infrastructure. The potential revenues from the sales of recyclable waste commodities are also sometimes overestimated. Municipalities often underestimate the logistical challenges of multiplying waste/recyclable streams and lack appropriate capacity to manage the recyclable waste that requires market assessment and commercial arrangements for sales of separated materials. As a result of such challenges, separate waste collection systems are often not sufficiently financed due to the difference between planned (expected) and actual costs and revenues.

The chapter demonstrates that once a decision is taken to introduce separate collection, alternative systems and collection methods should be considered. Different collection methods result in different quantities and quality of collected waste fractions and have different investment and operating costs. For example, bring systems require more efforts from citizens to reach the containers and discard sorted fractions and show relatively high level of impurities. Curbside systems on the other hand achieve higher collection rates and better quality of material collected but are more expensive. The chapter presents cost examples for different collection systems and container sites. For example, it shows that a collection scheme using individual plastic bins has the highest implementation cost but results in higher quantities and good quality of collected materials.

Similar to other waste management operations, economies of scale exist when organizing separate collection of recyclable waste. For that reason, recycling programs are usually focused on large urban settlements and then extended to neighboring areas.

It is important to note that separate collection and sorting of household recyclable waste is a net cost activity, that is, the revenues from the sales of recyclable material are often lower than the combined costs for separate collection and sorting. For that reason, economic instruments and/or EPR schemes are often required to provide additional financing.

The separate collection costs per capita served in the urban areas according to the examples provided in these guidelines are expected in the range of \$2.5–\$5.0 per resident per year. The costs per capita served in rural areas are considerably higher due to the smaller waste quantities generated/collected and higher transportation distances. These costs do not include the public awareness costs estimated in the range of \$0.5–\$1.5 per capita at least in the first years of operation or until the separate collection system is fully settled. It should be noted that costs per tonne of recyclable waste collected are different for the different materials/fractions and could vary considerably depending on quantities collected, residents' participation, and the achieved capture rate.

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[4] GIZ. 2022. *Guideline on Separate Waste Collection and Sorting of Recyclable Municipal Waste.*

Sorting of separately collected recyclable waste

Typical problems faced in planning and operations of sorting facility for separately collected waste are usually related to inappropriate capacity or design. The capacity could be too small for the quantity of input waste fractions, for example, due to high quantities of material assumed to be separated by worker at the sorting line or insufficient number of sorting lines. In the opposite case, the installed sorting capacity is overestimated, and the facility could process much higher quantities than actually delivered on site.

The sorting facilities are usually established for separately collected paper and cardboard, different kinds of plastic waste, and metal packaging. The separate collection and sorting of glass should be analyzed independently. In many countries there is no developed glass industry and the recycling possibilities are limited. Typically, the separately collected glass fraction requires a special sorting/treatment plant with a significant input capacity of 50,000 tonnes and beyond to be economically justified. Solutions that use waste glass in the production of concrete and construction materials are often considered as alternative to traditional recycling.

The simplest sorting facilities comprise of manual picking station and baling presses that could be provided in different configurations and capacities. Small sites equipped with vertical baling press are usually intended for processing small quantities of 30–60 tonnes of waste per month and served by few workers, while large sorting plants could process several thousand tonnes per month.

The chapter provides two examples of sorting facilities with different capacity. The examples show that significant economies of scale exist with the increase of sorting capacity. Construction of small size installation processing only few tonnes of recyclable waste per day should be avoided. It should also be noted that better sales prices can be achieved for larger quantities of recyclable materials.

If properly designed, the revenues from the sales of recyclables should exceed the sorting costs but in most cases will still not be sufficient to cover the combined separate collection and sorting costs. It should also be noted that the market of recyclable waste is dynamic and significant price fluctuations are observed even within short periods.

Performance indicators for sorting efficiency should be established at the beginning of operations. Typically, these include quantity of separated materials per unit input waste (sorting efficiency), costs per tonne of separated material, revenues per tonne of separated material, and others.

Composting of separately collected green waste

Composting of organic waste is a controlled biological process in which organic materials are broken down by microorganisms. Composting installations could be implemented in various sizes and capacities and different technologies (with varying costs) exist, for example, static pile, open windrows, aerated piles, and different in-vessel composting (IVC) systems based on tunnels, containers, bays/beds, silos, and rotating drums. The different technologies require different durations to produce compost that has impact on the area required. The selection of composting technology depends on the type and quantities of input waste, the legal requirements in place, climate conditions, site characteristics, and other conditions. While the open windrow composting and aerated piles are well-proven technologies for green and market waste, the presence of food waste in the input material requires using covered or closed composting systems to properly manage emissions and odors.

The chapter discusses typical shortcomings observed when planning composting systems, such as contamination of collected green/biowaste as a result of which the produced compost does not meet the planned quality requirements and projected revenues and demand for compost are much lower than initially planned.

The key considerations when planning composting systems are also discussed, including whether to give priority to home composting or to implement separate collection of green and other biowaste; whether to implement centralized composting installation or smaller decentralized sites; and what type of composting technology, equipment, and site design requirements will be optimal for the type and quantities in the specific case. In general, home composting is the appropriate solution for rural areas while composting installations usually serve more densely populated areas. The composting can be organized through centralized large-scale facilities usually accepting several thousand tonnes of waste per year or decentralized to several small sites where few hundred tonnes of waste are treated close to the place of generation. If the decentralized model is applied, usually mobile equipment is used for shredding, turning, or sieving.

The chapter provides two cost estimate examples for green waste open windrow composting sites with different sizes. Windrow composting installations demonstrate significant economies of scale, and larger facilities processing several thousand tonnes per year have lower unit costs. The chapter also provides summary cost estimates for composting installations using IVC in tunnels and aerated static pile (ASP) technologies for the intensive phase of the process, and open windrows are used for compost maturation. In the examples given, the ASP composting shows comparable costs to windrow composting while composting in closed system is considerably more expensive.

It should be noted that the possible technical solutions and equipment used could vary significantly even for composting sites that have same capacity and employ similar technology. Potential revenues from compost depend on quality, demand, and available outlets. There are many examples in LICs and MICs where composting installations ceased to function due to lack of market and expected revenue stream. On the other hand, it is noteworthy that the revenues sales could be significant if the compost quality is guaranteed by recognized certification scheme.

Anaerobic digestion

Anaerobic digestion (AD) is a technology for controlled anaerobic treatment of biodegradable waste used to transform the organic matter contained in the waste into biogas and digestate valuable as an organic fertilizer or soil improver. In municipal waste management, the AD is mainly used for recovery of separately collected biowaste. It is also used outside the municipal waste sector for wastes high in chemical oxygen demand (COD) and as a treatment process for sewage sludge. The production of biogas from controlled AD is one of the principal advantages of the process. It is a renewable energy source that can be used to produce electricity, heat, and fuel (gaseous or liquefied).

The main AD technologies used are wet digestion, dry continuous digestion, and dry batch digestion.

The characteristics of the feedstock have significant impact on the AD process and therefore on the biogas yield and the digestate quality. Uncertain quantities and composition of input biowaste and possible contamination could be a significant challenge for the AD operation.

The AD plants can be of different capacities starting from several hundred tonnes per year to hundreds of thousands of tonnes per year. In some developing countries, AD is also applied at a small scale where large number of small facilities are used by one or several households to produce small quantities of gas used for cooking.

The chapter provides summary cost examples for AD plants with different capacities for separately collected biowaste. In principle, AD is an expensive technology with high investment and operating costs that considerably exceed the costs for aerobic treatment (composting) for the same installed capacity. The high costs are compensated to a large extent by the revenues from the sales of electricity produced or gas provided to public network, but this is only possible for large-capacity installations. The revenues could be considerably higher if preferential tariff applies for electricity produced from renewable sources. The conditions and costs for connection to electricity grid (in case of electricity production) should also be well analyzed during the site selection and feasibility stage.

The construction of an AD facility requires well-functioning separate collection system of biowaste to guarantee the feedstock. Appropriate pretreatment of input biowaste is required to remove plastic bags and other impurities not desirable for the process. The O&M of a complex AD facility also requires the availability of qualified personnel and specific skills.

Treatment of residual/mixed municipal waste

Material recovery facilities (MRFs) and MBT plants have been considered for treatment of mixed (residual) municipal waste and production of refuse-derived fuel (RDF). Besides shredding, sorting, screening, and so on to separate the recyclable waste fraction, additional biological treatment and mechanical processes apply at the MBT stage.

The chapter provides two examples of MBTs of the same size: one where high-calorific RDF is produced and the biotreated fraction is designated for landfill, with or without production of compost-like output (CLO); a second one designated to maximize the RDF production and minimize the quantity of treatment residues designated to landfill. In both examples, the mechanical treatment of input waste is organized in a similar way. The biological treatment in the first case aims to stabilize the material, and the majority of combustible fraction contained in the dried waste is separated using different separation techniques for RDF production. The treatment residues containing mainly mineral fraction are designated to landfill. In the second case, bio-drying is used. Sample cost estimates are provided for both scenarios.

It should be noted that the resulting high-cost estimates reflect the assumed technology of the installations. Simplified treatment concepts could be considered when limited funds are available and two additional examples of such simplified MBT plants of the same capacity are also presented to demonstrate possible costs reduction. In this case, the industrial halls are replaced with shelters and biofilters and other equipment for treatment of exhaust gases are removed; ventilation is limited only to sorting cabins; the MBT tunnels are replaced with open ASPs; and some of the expensive equipment modules (optical sorting and eddy current separators) used to produce RDF are removed. The resulting cost estimates are considerably lower.

It should also be noted that such cost reduction is achieved as a result of removing some process equipment, applying lower standards for emissions and smell reduction from installations, relaxing labor safety requirements, and so on. As a result, such lower-cost solutions have some disadvantages compared to more 'standard design' facilities and may not be able to provide the same operational characteristics, ensure flexibility to changes in input waste quantities and composition, and guarantee the quality of output products.

The chapter lists some of the key challenges when planning waste treatment facilities, usually related to uncertain quantities, composition, and granulometry of input residual waste and overoptimistic projections of recycling potential of input waste and capture/separation rates achieved, resulting in overestimated revenues since the quality of separated recyclable materials, RDF, and CLO could not be in line with market demand and requirements of the final recipients.

It should also be taken into account that the materials separated for recycling out of the mixed municipal waste are of lower quality than the separately collected recyclables and the demand and market prices for such materials will be lower. Revenues from the sales of RDF are not certain and price could be negative if quality requirements are not met.

Costs of the entire waste management system

Chapter 4 starts by demonstrating that significant economies of scale are associated with larger sites and this affects total waste management costs per tonne of waste collected and the cost per household, as reflected in the tariff.

The costs calculated in Chapter 3 for each waste management component are then brought together to show examples of a total waste management system. The purpose is to demonstrate and compare several collection and treatment options for a regional municipal waste management system serving all sample municipalities (catchment areas - CAs) listed in Chapter 2, with a total population of 1.4 million residents.

In doing so, investment and O&M cost data are input on an annual basis across a fixed operational period. Investment cash flows include the initial investments and reinvestments to replace equipment at the end of its economically useful life. Specific details of each system component are retained within the analysis. For example, line items covering sorting plant's O&M costs are recorded separately and then aggregated with the costs of all other waste components into a system total for the specific cost item.

The following five alternatives and two sub-alternatives are compared in terms of costs:

i. *Alternative 1* provides basic municipal waste collection services organized at the municipal level where all collected municipal waste is disposed of to a central regional landfill.

ii. *Alternative 2* builds on the previous alternative and adds additional services: separate collection of recyclable waste and composting of green waste collected from public parks and green areas. All residual/mixed municipal waste is collected and delivered to a regional landfill. The reduced quantities of waste designated to landfilling compared with the previous alternative are taken into account when calculating the necessary landfill capacity and costs.

iii. *Alternative 3*. The third alternative retains the waste collection, separate collection, and composting elements considered in the previous alternatives but all residual waste is designated to an MRF where additional recyclables are separated, and RDF is produced.

iv. *Alternative 4*. In the fourth alternative, the MRF is upgraded to an MBT plant producing high-calorific value RDF and CLO. Two variants of Alternative 4 are considered. In Alternative 4a, the entire mechanical part and intensive phase of biological treatment is installed in closed industrial buildings. Alternative 4b has treatment steps similar to Alternative 4a but the equipment is installed in an open area under a shelter and a simplified treatment concept is used for the purpose of cost reduction.

v. *Alternative 5.* In this alternative, a different technology for MBT plant is considered, based on bio-drying. The changed treatment technology's main objective is to maximize the production of RDF and ensure no CLO is produced. Alternative 5a is for an entirely closed plant while Alternative 5b provides a lower-cost solution where the process equipment is installed under a shelter and some of the more typical RDF processing steps are not applied.

Detailed mass balances and cost estimates are prepared separately for the different waste operations for the whole waste management system under each alternative described above. The comparison demonstrates the various cost requirements for the different alternatives which may have varying objectives, such as maximizing diversion from landfill or production of RDF. It shows that the construction of MBT under the last two alternatives results in more considerable reduction of landfill waste; however, the investment requirements increase with the extension of separate collection system and application of more advanced treatment technologies for residual/mixed municipal waste.

The analysis shows that total unit costs per tonne of waste generated considerably increase with the establishment of separate waste collection and composting and increase further with the implementation of more advanced treatment for residual waste such as MRF and MBT. If revenues from the sales of recyclables are considered, the costs increase is partly compensated and the resulting net costs show smaller differences between alternatives. Such conclusion should be interpreted with caution because the revenues are not guaranteed and are influenced by many factors as explained in Chapter 7.

The chapter seeks to impress that waste management operations are interdependent and understanding the costs of the entire waste management system is required. Potential benefits of economies of scale in establishing common treatment and disposal facilities serving several neighboring municipalities should be assessed and common benefits identified at the planning stage.

Average incremental cost (AIC) analysis for municipal waste management

Chapters 5 to 7 cover some powerful costing techniques that can be readily applied to many situations found in domestic waste management: understanding the financial structure of the waste system; evaluating technical options and their cost implications for tariffs and revenue; assessing the financial viability of schemes to collect, sort, and sell recyclable materials; and undertaking longer-term planning, budgeting, and tariff analysis.

Chapter 5 introduces the concept of AIC analysis and the insights it can bring to effective financial management and planning. It shows how an understanding of unit costs can be invaluable for systematically analyzing and comparing the costs of waste system options and components, how to translate an irregular cost flow into a smooth revenue flow with the same current value as the cost flow, how to define the relative contribution made to total costs by each waste function, and how to define a uniform gate fee for an MRF plant when full capacity utilization is to be phased over time.

Chapters 5 to 7 take as an example Alternative 2 presented in Chapter 4 and draw on analysis undertaken with the cost model for each municipality/catchment area defined by population size and for five waste management functions (separate collection, residual waste collection, composting green waste, sorting separately collected material, and landfill operations). Net cash flows, AICs per tonne and per capita, and their equivalent annual revenue flows are estimated. Unit costs of separately collected waste and recyclable materials sorted are assessed. The analysis is carried out in constant 2022 values and based on a 12-year planning period.

The analysis is undertaken using the techniques of discounted cash flow (DCF) analysis; AIC analysis is an extension of this. AIC analysis enables the full costs of service provision to be allocated over the planning period pro rata to the quantity of waste (or recyclable material) managed each year. The aim is to define a revenue flow which has a present value (PV) equal to the PV of the net cash flow, that is, a discounted revenue flow which is equal to the discounted cost flow, and hence covers projected costs in full.

The annual revenue requirement refers to the revenue needed annually over the planning period to cover system costs in full. This does not mean that costs must be recovered in full from user charges but that any gap between the revenue requirement and revenue from user charges must be covered by other sources of funds (such as municipal transfers).

AIC analysis techniques can be used to provide estimates of absolute and relative unit costs:

i. By function, such as the direct cost per tonne of material sorted at an MRF plant (a measure of the ***absolute*** or actual unit cost of the function or activity per tonne of material managed).

i. By the contribution the unit cost of a system component makes to total system unit costs ***relative*** to the unit cost contributions of all other components measured against the same base (for example, per tonne of total waste generated).

The example used in the chapter demonstrates that significant differences can exist between absolute and relative AICs for some functions, whereas for others they are small. Both absolute and relative values are powerful tools to assess the planned waste management system in terms of cost and revenue requirements.

Approaches to estimating residential waste tariffs

Chapter 6 starts by outlining three approaches to calculating residential waste management tariffs—per capita, based on AIC techniques, and based on traditional accounting (TA) techniques. The approaches result in different unit costs, revenue flows, and indicative tariffs per capita but all generate revenue flows with (almost) identical PVs. The first and most valuable approach based on an AIC per tonne is a simple extension of the AIC analysis described in Chapter 5. The second, based on an AIC per capita, is even simpler to calculate but suffers from significant drawbacks. The TA approach is based on traditional accounting concepts (depreciation, return on investment [ROI], and operating costs) and is commonly used for setting tariffs in a specific year with only limited consideration to future service demand or capacity constraints. But it can also be used for evaluating existing services or planning new ones over time. It also has serious drawbacks which limit its use over time. The chapter concludes with sections on affordability and financial sustainability and fixed and variable costs.

The AIC per tonne of waste generated is used to calculate the annual revenue requirement—this being the product of the AIC per tonne and annual waste quantities in tonnes. The PV of the annual revenue requirement is then identical to that of the net cash flow. The annual revenue requirement is then divided by the annual population (held constant over the planning period) to give a starting indicative tariff in the base year rising over time. The rise in the tariff profile results from increasing waste generation per capita. The approach leads to lower tariffs in earlier years and to higher tariffs in later years, reflecting the user pays principle (rising waste quantity generated per capita).

Both the AIC per tonne and the TA approaches define an annual revenue flow that covers total costs in full. They differ in the way investment costs are recognized. This is in turn reflected in the way annual revenue requirements are defined and in the tariff profiles created from them. To recap, the AIC per tonne approach is based on the estimated annual investment costs, the residual value of the assets created by the investments, annual operating costs, and the discount rate used to discount the future cash flows to their PVs. The TA approach is based on depreciation of the assets created by the investments, the financial return on those investments, annual operating costs, and the relevant rate for calculating the ROI (taken to be equal to the discount rate). Identical revenue streams are generated in PV terms, but the timing of the revenue requirements is different.

The TA approach leads to erratic and falling tariffs over the planning period whereas the AIC approach results in progressively rising tariffs consistent with rising populations and increasing waste generation per capita. It should be noted that the AIC approach depends critically on the availability of accurate data on current and projected population numbers, per capita waste generation, and per capita incomes.

Revenue from the sale of separately collected and sorted material

A key objective of many local municipalities is to recover value from materials contained in the waste stream. Although separation at source is increasingly becoming a legal requirement, implicit in this is a desire to generate profits which can contribute to the costs of the wider waste management system.

The first part of **Chapter 7** sets out some commercial factors to be aware of when considering setting up separate recyclable waste collection, sorting, sales, and marketing facilities. The second part draws on waste and material and revenue and cost flows introduced in earlier chapters to assess the financial performance of a separate material collection and recycling scheme. The analysis relies heavily on unit costs and PVs derived using the AIC approach.

The materials recovery and sales component is part of the total municipal waste management system, its costs form part of total system costs, and its sales revenues contribute to the total revenue needed to cover system costs in full. The materials recovery and sales system is assessed from the perspective of a separate, standalone commercial entity. This is followed by a general commentary on the financial viability of material recovery schemes together with some summary notes to help guide decision-making in this area.

It should be remembered that collecting recyclable materials separately avoids the need to gather and dispose of them to landfill. That is, mixed waste collection and landfill disposal costs are reduced. These avoided costs should be fully recognized when assessing the net costs of the materials recovery system. However, the full costs of service provision are not avoided if material is diverted from the residual waste stream to the separate collection of recyclable material.

Revenue from the sale of recyclable materials is subject to two main risks: the quantity of recoverable material in the separately collected waste and markets for the materials recovered. Unless driven by mandatory obligations, materials recovery systems should be implemented when there is a high level of confidence that a realistic and predictable supply of recoverable material is available for collection and proven markets exist for the recovered materials.

Concern over waste composition comes from an awareness that informal collectors can often retrieve a large share of the valuable material before it can be formally collected. If this is the case, then the material quantities on which the sorting plant capacity and the sales analysis are based may be unrealistic. This factor is crucial to the assessment of any materials recovery scheme. Data on the composition of the waste stream available for formal collection are generally poor.

Markets for materials recovered from municipal waste are often poorly developed, with assumptions on product markets, sales potential, and selling prices being speculative and uncertain. A reliable market analysis of the potential for recyclable material sales should be undertaken in the planning phase. The prices of recyclable waste commodities also vary considerably over time.

Importantly, it should be recognized that municipal waste management is a net cost activity. The extensive systems of waste material recovery found in high-income countries today are a result of legislation that imposes strict and binding waste management targets on local authorities.

The **annexes** to these technical guidelines define and explain the categories and types of costs used in the cost analysis. It is recognized that municipal waste management services are characterized by a high share of fixed costs in their overall cost structure and describe the implications of this for charging structures and revenue stability. The broad concepts of DCF analysis, cost-effectiveness analysis, and AIC analysis are outlined—these being powerful tools for analyzing the relative costs of system components and for calculating unit costs and tariffs.

A **Glossary** of financial terms used in this document is also provided.

1 Introduction and overview

1.1 Introductory comments

Municipal Solid Waste Cost Calculation Technical Guidelines discusses good practices for calculating investment and operating costs in the solid waste[5] management (SWM) sector. The document includes illustrative examples of notional cost calculations for selected waste management functions and for a combined waste management system.

The guidelines—using a step-by-step approach and set input data—demonstrate how the costs of each of the main municipal waste management functions are calculated and how changes in operational and/or technical requirements affect cost levels. They then show how the outputs from the initial cost analysis are combined to establish the total investment and operating costs of a notional waste management system. These are then used to determine indicative annual revenue requirements and full cost recovery tariffs. Outcomes from the analysis can also be used to answer several questions: are the proposed services affordable to users and municipalities; are they financially viable; is external grant funding needed; does the scope and scale of the envisaged system need to be re-examined?

The publication aims to impress that funding annual operating expenses—typically higher than the annualized capital costs of investments and the single most important factor for sustaining waste operations—needs to be a key area of attention for local authorities. It emphasizes that the waste management sector is principally a net cost activity that requires financing; while investments in advanced treatment facilities and processes bring higher environmental and economic benefits, they also incur higher financial costs and hence revenue requirements.

The document was prepared in response to interest expressed by many municipalities across geographic regions in receiving guidance to determine their operating costs from local unit rates. The publication aims to demonstrate the approach of establishing costs and support the work of technical departments within municipalities that inform, advise, and guide their municipal councils and policy makers in planning their waste systems, justifying and setting tariffs, and mobilizing finance. It is expected to assist municipalities in operating current systems more efficiently and improving mu-

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[5] 'Municipal solid waste' means (a) mixed waste and separately collected waste from households, including paper and cardboard, glass, metals, plastics, biowaste, wood, textiles, packaging, waste electrical and electronic equipment (WEEE), waste batteries and accumulators, and bulky waste, including mattresses and furniture and (b) mixed waste and separately collected waste from other sources, where such waste is similar in nature and composition to waste from households. Municipal waste does not include waste from production, agriculture, forestry, fishing, septic tanks, and sewage network and treatment, including sewage sludge, end-of-life vehicles, or construction and demolition waste. Waste from markets, bulky waste, and garden and park waste are also considered part of municipal waste.
'Biowaste' means biodegradable garden and park waste; food and kitchen waste from households, offices, restaurants, wholesale, canteens, caterers, and retail premises; and comparable waste from food processing plants.
The definitions are aligned with Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives, also referred as European Union (EU) Waste Framework Directive (EU WFD) as well as definitions adopted by the Organisation for Economic Co-operation and Development (OECD), United States Environmental Protection Agency (US EPA), and the 'What a Waste 2.0' report produced by the World Bank (2018).

nicipal capacity to plan system improvements and expansions beyond current levels. The guidelines were developed with consideration of the state of the sector and its development trajectory in low- and middle-income countries (LICs and MICs).

1.2 Current and future service costs

The majority of municipal SWM departments in LICs and MICs are unaware of the full costs of their services or how to calculate them. Only rarely are costs allocated against specific service functions (such as waste collection or landfill operations) and many are recorded (if at all) on a line-item basis with related services, such as drain cleaning, street sweeping and repairs, and snow removal. Separate financial and accounting records are not kept, and costs when needed—for example, to prepare a budget—are based on rough estimates at best. Costs often reflect predetermined norms for waste generation, unit input costs, and tariffs. They are rarely based on real, current, empirical data taken from recent experience or market prices.

Problems with cost accounting also arise because waste service costs are often combined and brought under general budget items or, the opposite, spread across a range of budget items.

Except for waste collection and transportation, data collected on municipal SWM cost items are inadequate. Taking landfill as an example, data on tasks such as compaction, cover, active gas capture, and environmental performance monitoring are typically not collected separately from other landfill activities. Asset depreciation is commonly not systematically recorded. As a result, treatment and disposal costs reported can be well below those reported by a professional organization using local unit rates. On the other hand, costs reported for collection and transportation are often observed to be higher than those reported for a professional and competent system. Such outcomes suggests that there are cost efficiencies to be exploited, such as trimming staff numbers or reducing high levels of cross-subsidy (municipal transfers), thereby creating efficiency incentives. In such cases, high costs for waste management services, particularly for waste collection, is a strong signal for inefficient spending of public funds.

Municipal waste management departments should know the full costs[6] of their municipal waste services and the various functional components of the waste system. Before a municipality can define its actual financing needs, it must first clearly define the full costs of its current services and then establish the incremental costs of planned new investments and operations. Although the largest single expenditure incurred in providing municipal waste services is typically for infrastructure investments, the most significant financial challenge is often to estimate the annual revenue requirement and determine how it should be funded. Annual operational expenditures (excluding depreciation) are often higher than the annualized capital costs of investments, with estimates showing them to account for 70 percent or more of total annual budgetary requirements.

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[6] Difference should be made between the 'full costs' and 'full costs recovery from users fees'. When practical and considering affordability constraints, in addition to the user fees, budget transfers and financing from other municipal sources could be used for covering waste management costs.

The financial costs of providing municipal solid waste services must be funded, one way or another. Users must ultimately pay for the services they use, either directly though user charges or indirectly through municipal transfers/taxes or a combination of the two. Municipal waste services should be appropriate, affordable, socially acceptable, and financially sustainable. This means that municipalities should be clear about the scope of the services being provided, the full costs of those services, and how those costs—both investment and operational—are to be funded. This information enables realistic decisions to be made on whether the services proposed can be operated and funded sustainably over time.

There are many reasons why municipalities should properly understand the full cost of the waste management services they provide and of the services they propose to introduce in the future. Reliable and comprehensive cost information is needed to define the full costs of current services, plan future strategy and services, prepare realistic capital and operational budgets, define the scope for cost recovery via user charges, and assess the financial implications of involving the private sector in service delivery. It also enables calculation of unit costs (for example, $/tonne of waste collected) for the total system and its component parts, thereby facilitating unambiguous cost comparisons between various system components (for example, an options analysis to define the net financial gain or loss to the combined waste management system of introducing a regional system of waste transfer stations or the financial implications of shifting from individual municipal collection services to a combined regional waste collection service).

It can be hard to secure financing for waste services if the full costs of service are not known—the single most important factor in sustaining operations. The municipal and higher-level authorities that typically approve financing for municipal waste management departments are more likely to approve requests to raise budget allocations and tariffs when they are supported by a full cost analysis. When requests are not supported in this way, budgets are likely to be assigned according to prior funding allocations and available municipal resources, which can lead to severe underfunding.

Without knowing the full costs of baseline services, it is also hard to plan system improvements. A current example is that of municipalities looking to introduce systems of waste separation at source in parallel with existing mixed waste collection and disposal systems. In the absence of a functional extended producer responsibility (EPR) scheme to finance the incremental costs, which is overwhelmingly the case in LICs and MICs, reliable data on the full cost of the existing mixed waste system should be the benchmark against which the incremental net costs of separation at source can be evaluated.

Once full costs are known, the annual revenue required to cover these costs can be established and indicative user tariffs estimated (for example, average cost per person or household). This does not mean that a full cost recovery charging system will be introduced but it does provide a powerful indicator of what the tariffs would need to be if a full cost recovery policy were to be introduced. If a partial user-based cost recovery system is proposed (for example, to cover operational or fixed costs only), the full cost analysis will help determine the balance of the municipal funds needed to cover the annual revenue requirement and for the services to be operated on a commercially sustainable basis.

1.3 Chapter outlines

The document is organized into seven chapters. It demonstrates how the full costs and the unit costs of individual service components (for example, residual waste collection and material recovery facility [MRF] operations) are calculated, how these are brought together to calculate the costs of the combined waste management system, how these are used to calculate the annual revenue needed to cover them, and how this information is used for setting user tariffs and charges.

Making such calculations requires understanding of how to apply the financial techniques of discounted cash flow (DCF) analysis and average incremental cost (AIC) analysis. These are outlined in Chapter 2 and further developed and illustrated in the analysis of total system and system component costs and annual revenue requirements presented in Chapters 5 and 6.

The scope of the guideline, following this introductory *Chapter 1*, is as follows:

Chapter 2: Defining the waste management system

This chapter lists the physical parameters that determine current costs and possible technical alternatives to be considered when formulating different scenarios to achieve future waste management objectives. It then outlines the approach followed in subsequent chapters. First, it lists the individual waste management functions or principal components of the waste system included in the cost analysis in Chapter 3 which include collection of residual/mixed waste, municipal waste transfer, landfilling of waste, separate collection and sorting of recyclable materials, home composting, separate collection and composting of green waste, separate collection and treatment of food waste, and sorting and Mechanical Biological Treatment (MBT) of residual waste.[7] Second, it lists the size of municipalities used for the subsequent examples of cost calculations.

Chapter 3: Cost factors for the main components of the waste management system

This chapter focuses on sample cost calculations and estimates for municipal waste components and scenarios outlined in Chapter 2. The summary results are presented to demonstrate the scale of costs for the different waste management operations and technical alternatives, while several detailed examples showing different inputs and outputs of the analysis are presented in the tables and figures. Descriptions of each functional component are provided, together with scenarios for illustrating the economy of scale effect on the total and unit costs of the alternatives considered.

The cost estimates for the different waste management operations are presented. These should be interpreted with caution as they refer to the specific examples presented and based on assumptions and unit costs used in these guidelines. If applied to specific local conditions, significant deviations in the scale of ±20 percent from the presented cost estimates can be observed due to the differences in waste quantities and composition as well as local and regional differences in the costs of labor, fuel, energy, construction, materials, civil works, and equipment. Such differences could be higher for waste management treatment and recovery operations such as composting, anaerobic digestion (AD), or MBT. It should be noted that major price differences are also observed between different manufacturers and unit prices for equipment, machinery and vehicles with otherwise comparable technical characteristics. Local legal requirements, norms for emissions discharged into the environment, specific design and construction requirements, labor safety, and fire protection standards could also have a significant impact on the applied technical solutions and the related construction and equipment costs.

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[7] Waste-to-energy (WtE) incineration is outside the scope of these guidelines.

Additionally, the cost estimates examples provided in the guidelines are based entirely on purchasing of new equipment. While it is acknowledged that secondhand equipment is often purchased in LICs and MICs and that equipment is operated well beyond its typical economical life (and therefore depreciation period), appropriate assumptions about lifetime and increased maintenance costs should be made when preparing respective cost estimates.

Chapter 4: Costs of the entire waste management system

Cost outcomes calculated in Chapter 3 for each waste management component are brought together in Chapter 4 to define a total waste management system. Investment and operation and maintenance (O&M) cost data are input on an annual basis across a fixed operational period. Investment cash flows include the initial investments; reinvestments to replace equipment at the end of its economically useful life, for example, construction of new cells at regional landfills; closure and recultivation of old cells; and closure and aftercare costs[8] that arise following closure of a landfill or waste treatment plant. Specific details of each system component are retained within the analysis. For example, line items covering sorting plant's O&M costs are recorded separately and then aggregated with the costs of all other waste components into a system total for the specific cost item.

Chapter 5: AIC analysis for municipal waste management

Chapters 5 to 7 cover some powerful costing techniques that can be readily applied to many situations found in domestic waste management: understanding the financial structure of the waste system; evaluating technical options and their cost implications for tariffs and revenue; assessing the financial viability of schemes to collect, sort, and sell recyclable materials; and undertaking longer-term planning, budgeting and tariff analysis. Chapter 5 introduces the concept of AIC analysis and the insights it can bring to effective financial management and planning. It shows how an understanding of unit costs can be invaluable for systematically analyzing and comparing the costs of waste system options and components: how to translate an irregular cost flow into a smooth revenue flow with the same current value as the cost flow, how to define the relative contribution made to total costs by each waste function, and how to define a uniform gate fee for an MRF plant when full capacity utilization is to be phased in over time. These and other questions are answered with the help of tables and diagrams.

Chapter 6: Approaches to estimating residential waste tariffs

The chapter starts by outlining three approaches to calculating residential waste management tariffs—per capita, based on AIC techniques, and based on traditional accounting (TA) techniques. The approaches result in different unit costs, revenue flows, and indicative tariffs per capita but all generate revenue flows with (almost[9]) identical present values (PVs) of today. The first and most valuable approach based on an AIC per tonne is a simple extension of the AIC analysis described in Chapter 5. The second, based on an AIC per capita, is even simpler to calculate but suffers from significant drawbacks. The TA approach is based on TA concepts (depreciation, return on investment [ROI], and operating costs) and is commonly used for setting tariffs in a specific year with only limited consideration to future service demand or capacity constraints. But it can also be used for evaluating existing services or planning new ones over time. It also has serious drawbacks which limit its use over

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[8] Note the need for 'advanced depreciation' to cover the costs in advance for the closure and restoration of a landfill cell.

[9] The two AIC-based approaches have identical PVs whereas the TA approach leads to marginally different outcomes due to limitations of accounting process. The differences are negligible.

time. The chapter concludes with sections on affordability and financial sustainability and fixed and variable costs.

Chapter 7: Revenue from the sale of separately collected and sorted material

A key objective of many local municipalities is to recover value from materials contained in the waste stream. Although separation at source is increasingly becoming a legal requirement, implicit in this is a desire to generate profits which can contribute to the costs of the wider waste management system. The first part of the chapter sets out some commercial factors to be aware of when considering setting up separate recyclable waste collection, sorting, sales, and marketing facilities. The second part draws on waste and material, revenue, and cost flows introduced in earlier chapters to assess the financial performance of a separate material collection and recycling scheme. The analysis relies heavily on unit costs and PVs derived using the AIC approach. A key consideration for operators with regard to system planning and revenue to sustain the systems is the cash flow in terms of time lag between an MRF sorting and recovering materials and receipt of moneys from the sale of materials, which can be a significant time that affects the viability of operating a separate collection and material recovery service.

Other topics covered in the chapter include recyclable material sales and risks, avoided costs and credits, the importance of knowing the difference between fixed and variable costs, and the competing objectives of affordability and financial viability.

The annexes to these guidelines define and explain the categories and types of costs relevant to the cost analysis. It is recognized that municipal waste management services are characterized by having a high share of fixed costs in their overall cost structure and describes the implications of this for charging structures and revenue stability. The broad concepts of DCF analysis, cost-effectiveness analysis, and AIC analysis are outlined—these being powerful tools for analysing the relative costs of system components and for calculating unit costs and tariffs. Outlines are provided on other issues having a bearing on waste systems outcomes and costs: affordability and financial sustainability; the relative costs of regional and municipal systems; recyclable material markets; and the influence of government policy in determining municipal waste outcomes: is municipal waste a net cost activity?

A *Glossary* of financial terms used in this document is also provided.

2 Defining the waste management system

This chapter lists the physical parameters that determine current costs and possible technical alternatives to be considered when formulating different scenarios to achieve future waste management objectives. It then outlines the approach followed in subsequent chapters.

The chapter has three sections. The first identifies core physical parameters that underpin the cost analysis:

- The planning period
- The service area
- Population sizes and projected change
- Household numbers
- Per capita/household income and projected growth
- Per capita waste generation and composition projections.

The second, on preparing a municipal waste management system and its technical components, entails the following:

- Compiling realistic waste generation and composition data over the planning period
- Undertaking waste flows analyses and mass balance calculations
- Defining future waste management objectives and targets
- Defining scenarios and technical alternatives for achieving municipal waste management objectives and targets.

Data on per capita waste generation and composition are fundamental to determining physical capacity requirements and sizing alternative waste collection and treatment facilities. Knowing the physical capacity requirements enables the resource cost requirements of municipal waste systems and their component parts to be calculated and allocated between capital expenditures (investments) and direct O&M expenditures (operational costs). General descriptions are given below, and the main cost factors established for the individual waste management components included in the cost analysis are as follows:[10]

- Collection of residual/mixed waste
- Municipal waste transfer
- Landfilling of waste
- Separate collection and sorting of recyclable materials
- Home composting
- Separate collection and composting of green waste
- AD of food waste
- Sorting and MBT of residual waste including with refuse-derived fuel (RDF) production.

The last section in the chapter lists the size of municipalities (catchment areas - CAs) used for the subsequent examples of cost calculations.

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[10] Waste incineration plants for mixed municipal waste are not included in the present guidelines.

2.1 Project parameters

Table 1 lists the project characteristics that need to be defined at the planning stage.

Table 1: Basic planning characteristics

Planning period	The planning period is usually between 5 and 30 years. It should correspond to the lifetime of the main assets. In case of large waste treatment and disposal infrastructure, such as landfills, MBT, or WtE plants, the planning period is usually 20 years and above. In case planning is limited only to waste collection services, the planning period is much shorter and usually corresponds to the envisaged contract duration, that is, 5–7 years for containers and 10 years for vehicles.[11]
Service area	Depending on the objective, the planning could be done at national, regional, or municipal level. For specific waste management activities, the planning could consider one or several districts within the same municipality, individual settlement or could be even done for a waste collection route.
Population sizes and household numbers in the defined area	Data about present number of residents living in the service area and respective number of households are needed for calculating waste generation.
Per capita (or household) income growth projections	Data about household incomes (or household expenditure) are needed for the assessment of affordability of proposed tariffs for waste management services.
Per capita waste generation and composition projections	Per capita waste generation and composition projections and their sensitivity to increase/decline in population numbers and increase in per capita incomes need to be determined. It is recommended that the waste generation data are presented separately for household waste and similar waste from commercial, industrial, or administrative origin. In addition, the impact of future waste prevention measures and global production and consumption trends (for example, replacing plastic food packaging with other alternatives) should also be considered.

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[11] Corresponds to assets lifetime/depreciation period.

2.2 The waste management system and its technical components

2.2.1 Waste generation data and waste generation forecasts

Reliable data about the waste quantities generated are the basis for development of reliable waste projections. Often the available information is limited to waste quantities collected and disposed of through the system managed by the local authorities. The estimates of generated waste quantities should consider all different sources and possible collection channels, including, for example, the recyclable waste collected by informal collectors, green waste collected from public areas, and illegally disposed waste.

Waste flow projections need to be prepared for the respective planning period. The projections should reflect both the total amounts of the different waste streams generated and expected changes in waste composition over the planning period. Specifically,

- Projections should be based on available data for waste quantity and composition, population growth, and expected economic development in the region.
- Projections should be prepared separately for urban and rural areas and consider differences in waste generation rates per capita and waste composition.
- To the extent possible, projections should distinguish between waste generated by households and similar waste of a commercial or non-process industrial origin.

- Projections should consider any other specific conditions at the regional or district level.

The following main factors influence the waste quantities and composition:

- Type of settlement (for example, large town or village)
- Type of buildings (for example, houses or apartments)
- Type of heating (for example, central heating, gas or coal based)
- Standard of living
- Household income
- Seasonal changes
- Local and regional economic, social, and cultural differences
- Consumer behavior
- Level of development of services in the respective area (commercial and non-process industrial waste).

Waste quantities and composition data are important to

- Define the necessary capacities for waste collection, treatment, and disposal, for example, total installed capacity, sizing of necessary technological equipment used in the respective treatment process (for example, screens and conveyor belts);
- Define the quantities of recyclable materials (recycling potential); and
- Ensure that the quantities of RDF and/or its heating value are not overestimated or underestimated.

2.2.2 Future waste management objectives and targets, waste flows analysis, and alternatives considered

The waste management costs are a function of the adopted technical and organizational solutions to achieve the waste management objectives in the respective planning area.

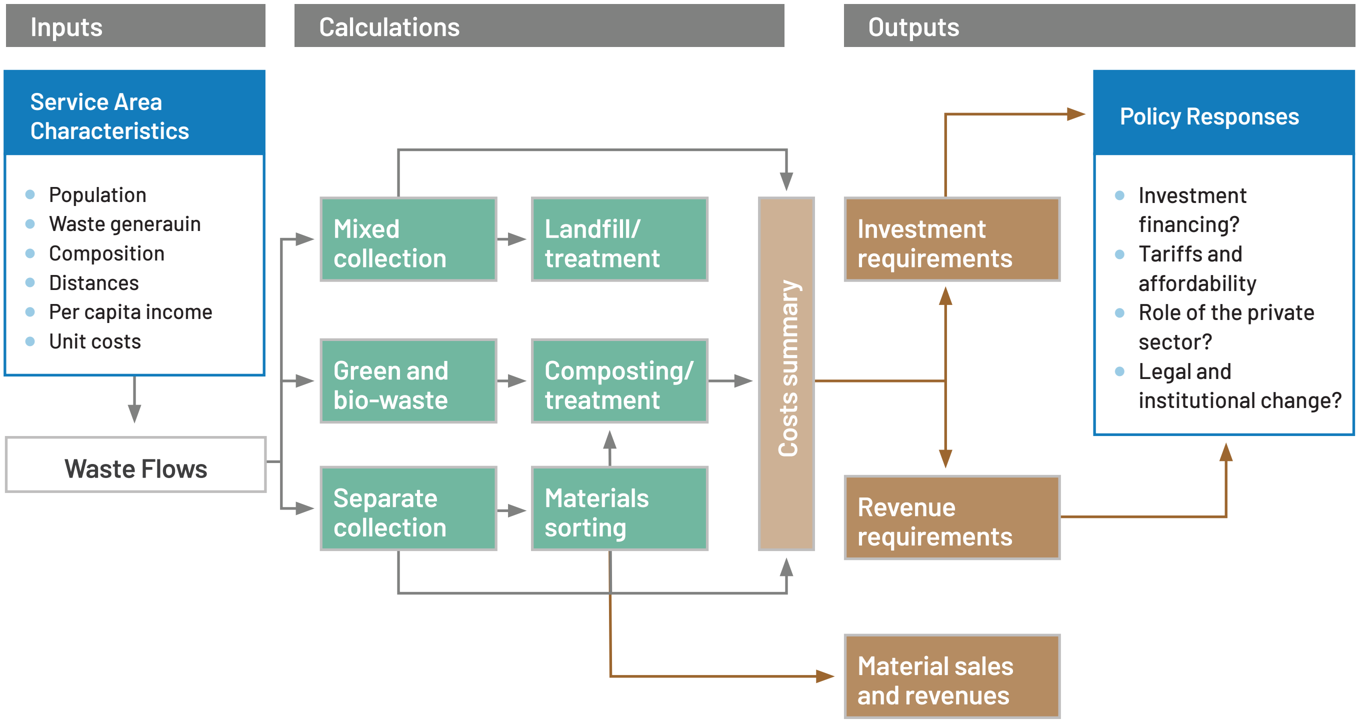
Developing cost estimates is preceded by defining the planning area, preparing population forecasts and projections of waste quantities and composition, defining the waste management objectives, and formulating technical scenarios for the different elements of the waste management system that allow the achievement of these objectives. Each of these has a significant impact on waste management costs.

Various options for waste collection and treatment should be prepared for the projections and mass balances of the quantities of municipal waste collected, separately collected, sorted, treated, recycled, recovered, and disposed of to a landfill. The analysis of waste flows and the projections form the basis for determining capacity requirements and for sizing the different collection and treatment options.

Selection of the optimal waste management option requires the identification and comparison of different technical alternatives for waste collection, recovery, and disposal. Figure 1 illustrates the data, calculations, and output parameters that need to be developed for each technical alternative to provide the basis for comparison and decision-making.

Social and cultural aspects can also play a role in waste management system design, for instance, in door-to-door versus bring systems for collection of recyclables, management of food waste, and centralized and decentralized composting systems.

Figure 1: Illustration of input data, mass flows, and cost parameters of a waste management system



Source: Own presentation.

Table 2 presents the main, though non-exhaustive, list of waste management activities and operations and possible technical alternatives to be considered when formulating different scenarios to achieve future waste management objectives. Typically, the waste management system is considerably simpler and does not include all activities listed below.

Table 2: Formulation of technical scenarios

Waste management operation	Alternatives to be compared	Outputs per municipality/service zone and average/ total for the entire planning area(s)
Residual/mixed waste collection	Considering different collection systems with regard to container type, volume, collection frequency, collection days per week, working shifts, working time, vehicles type and payload, and so on. Alternatives for dividing the planning area in several service zones where the same or different collection systems can apply.	Calculation of required number of containers and collection vehicles, estimated number of operational personnel for each service zone and the entire planning area. Calculation of investment costs per category of assets and operating costs per economic elements over the planning period, unit costs per tonne of waste generated/collected, unit costs per resident/household served, and unit costs per container served. Cost estimates should be prepared separately for services provided to households and those for legal entities. The cost estimates should be prepared separately for each service area/administrative unit and presented as total and average for the entire planning area. The quantities and cost estimates for the collection of bulky waste and street cleaning waste should also be presented separately.

Table 2: Formulation of technical scenarios (cont.)

Waste management operation	Alternatives to be compared	Outputs per municipality/service zone and average/ total for the entire planning area(s)
Waste transfer and long-distance transportation	Comparison of direct transportation of collected waste with the establishment of one or several transfer stations. Considering different technical and technological alternatives for transfer, for example, with or without compaction.	Calculation of investment and operating costs related to waste collection and transfer over the planning period, unit costs per tonne of waste collected/transferred.
Separate waste collection of recyclable waste	Formulation of alternatives with regard to separately collected fractions. Usually these include paper and cardboard, plastics, glass, and metals. Other fractions such as textile waste could also be included. Formulation of alternatives with regard to the number of residents/households provided with separate waste collection services over the planning period. Considering different separate collection systems with regard to container type, volume, collection frequency, collection days per week, working shifts, working time, vehicles type and payload, and so on. Alternative separate collection systems based on plastic bags or recycling/buy-back centers are also possible. The percentage of impurities (nonrecyclable waste) to be thrown in separate collection containers must be considered. Civic amenity sites (if relevant) are usually presented as separate cost item. Alternatives for 'bring' separate collection systems and curbside collection. Alternatives for dividing the planning area into several services zones where the same or different separate collection systems can apply.	Calculation of required number of containers and collection vehicles, estimated number of operational personnel for each service zone and the entire planning area. Quantities of separately collected fractions. Calculation of investment costs per category of assets and operating costs per economic elements over the planning period, unit costs per tonne of waste generated/separately collected, and unit costs per resident/household served. Separate collection costs could also include communication and public awareness component. Cost estimates should be prepared separately for services provided to households and those for legal entities.
Sorting of separately collected waste	Different alternatives for sorting of separately collected fractions, when relevant. For example, the sorting of paper and cardboard could be organized in a common or separate sites, the sorting and treatment of separately collected glass packaging is usually organized at large-scale facilities and alternative solutions with regard to capacity, location, and output quality/ treatment technology must be considered.	Required sorting capacities for the different separately collected fractions. Calculation of investment costs per category of assets and operating costs per economic elements over the planning period, unit costs per tonne of waste generated/treated/separated, and revenues from sales of separated recyclable waste commodities. When relevant, the costs should be designated to individual waste fractions.
Home composting, separate collection, and composting of green waste	Different alternatives for composting green waste.[12] Composting on site, decentralized composting systems, centralized composting. Different alternatives with regard to separate collection system for green waste.	Quantities of green waste generated, composted on site of generation (home composting), and separately collected. Investment and operating costs for the establishment of composting facility. Unit costs per tonne of waste generated/per tonne of input material/per tonne of compost produced.

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[12] While it is possible to compost food waste in open windrows, in particular when combined with green waste, it is recommended that post-consumer food waste is only composted by this means when collected through a separated source collection service and where the facility has mechanisms to control emissions (that is, biofilter with negative air suction through windrow) and robust procedures to ensure elimination of pathogens.

Table 2: Formulation of technical scenarios (cont.)

Waste management operation	Alternatives to be compared	Outputs per municipality/service zone and average/ total for the entire planning area(s)
Home composting, separate collection, and composting of green waste (cont.)	Different composting technologies (for example, windrows, aerated piles, and composting under roof versus open area)	Projected revenues from the sale of compost (if expected).
Separate collection and treatment of food waste	Considering different alternatives for separate collection of food waste considering the type of settlement and buildings in the area. Establishment of AD facility or closed composting systems for collected biowaste. Possible treatment with other waste types - sewage sludge, animal manure, green waste.	Quantities of food waste generated and separately collected. Investment and operating costs for the establishment of AD facility and/or closed composting. Unit costs per tonne of waste generated/per tonne of input material. Projected revenues from the sale of electricity, heat, and materials produced.
Sorting and/ or treatment of residual waste	Formulation of different technical solutions for sorting and treatment of residual waste. The simplest alternative could consider the separation of recyclables of mixed waste and could be extended with separation/production of RDF. In case MBT is considered, different technological and/or technical solution should be compared. Considerations about plant working time and availability (working hours, number of shifts) and flexibility (number of processing lines, treatment technology, and possible future adaptations) must be taken into account. For large agglomerations, alternatives with regard to the number, location, and treatment capacity should be considered.	Required treatment capacities. Calculation of investment costs per category of assets and operating costs per economic elements over the planning period; unit costs per tonne of waste generated/treated/separated; revenues and/ or costs from sales of separated recyclable waste commodities, RDF, MBT, and compost-like output (CLO).[13] When relevant, the costs should be designated to individual waste fractions or output materials.
Landfill	Formulation of different alternatives for the number, service area, and location of landfill. Different alternatives for leachate treatment on site and landfill gas utilization should be considered at feasibility or design stage.	Required landfill capacity over the planning period, required area for individual landfill cells and the entire site. Calculation of investment and operating costs over the planning period, including costs for closure, monitoring, and aftercare. Calculation of unit costs per tonne of waste generated/deposited on site.
Other waste management functions and costs	Collection of bulky waste, separate collection of household hazardous waste, other specific waste fractions.	The collection of bulky waste can be presented as separate cost estimates or included in the collection of residual waste as out-of-schedule service.

It is obvious from the table above that if the entire waste management system in the service area is considered, it will be practically impossible to analyze all possible combinations of alternatives for the different waste management operations. Instead, the approach is to consider separately the alternatives for the individual waste management operations and to analyze the costs for the entire waste management system for a limited number of possible scenarios.

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[13] Although CLO from MBT facilities shares a similar processing as compost, the two outputs should not be confused. CLO is generally not suitable for land application and therefore should not be confused with source-separated green or food waste compost. CLO rarely has a marketable sales value and the benefit is in stabilizing the material to make it relatively inactive and therefore cheaper to transport and manage in a landfill (produces far less gas and leachate, requires less compaction work, and results in less landfill settlement).

2.3 Project parameters and scenarios used for sample calculations in subsequent chapters

For the present document, five service areas with population of, respectively, 10,000 residents, 50,000 residents, 100,000 residents, 250,000 residents, and 1,000,000 residents have been considered.

The examples in Chapter 3 present various segments of the waste management system (for example, mixed and separate collection, transfer, various treatment, and disposal) for some of the above five service areas. Chapter 4 presents the overall costs for the entire waste management system if the service is organized at the regional level for all the above municipalities (that is, population of 1,410,000 waste generators). This has been done under several scenarios for waste collection and treatment. Specifically,

- The samples for *residual/mixed municipal waste* collection services in Section 3.1 are provided for a municipality with 100,000 residents, of which 70,000 live in urban areas and 30,000 live in rural areas. Some of the examples that showcase the sensitivity of various cost items refer to urban or rural residents only.
- The examples for *municipal waste transfer* are presented in Section 3.2 for a municipality with 100,000 residents and is used for collection of residual municipal waste. Additionally, costs for municipal waste transfer for a service area with 1,000,000 residents are provided.
- Sample costs estimates for *municipal waste landfills* with different capacities are provided in Section 3.3. The presented landfill capacities correspond to municipalities in all five service areas, that is, ranging from 10,000 through 1,000,000 residents.
- The samples for different *separate collection systems for recyclable waste* provided in Section 3.4 refer to 70,000 residents living in urban areas of a municipality with 100,000 residents (same as in the case of collection of residual municipal waste). The estimates for organizing separate collection in municipalities with different sizes are also shown as part of the overall waste management costs for a regional system serving all five sample municipalities (presented in Chapter 4).
- Examples of *sorting facilities* with capacities of 150,000 tonnes/year and 10,000 tonnes/year are provided in Section 3.4. The first case corresponds roughly to a service area with population of 1,410,000 residents, that is, all sample municipalities considered, while the second case is for a municipality with 100,000 residents.
- The examples for *composting installations* with different capacities are shown in Section 3.5. The capacities correspond to the quantities of green waste from public parks and gardens and maintenance of green areas collected in municipalities with 100,000, 250,000, and 1,000,000 residents.
- Section 3.6 presents examples of AD installations with capacities of 22,000 tonnes and 130,000 tonnes per year that roughly correspond to 50 percent of food waste generated in municipalities with population of 250,000 and 1,410,000 residents.
- Section 3.7 presents different alternatives for treatment of municipal waste for municipalities with total population of 1,410,000 residents, including MRF and MBT plants.

Unit rates used in the sample calculation (for example, waste generation/capita, waste composition, salaries, and cost for fuel) are listed in Annex 1.

3

Cost factors for the main elements of the waste management system

The presented unit and overall costs are calculated for the assumptions made and based on assumed, specific parameters as provided. Listed costs should therefore be interpreted in their own context and must not be regarded as overarching or applicable across geographies or income groups.

Chapter 3 presents sample cost calculations and estimates for each municipal waste component referred to in Section 2.3. Descriptions of each functional component are given, together with scenarios for illustrating the economy of scale effect on the total and the unit costs of the alternatives considered.

3.1 Collection of mixed/residual waste

The collection and transport system to be implemented should be defined separately for each service area and comprises the following major elements:

- Collection system
- Container volume and container placement system
- Collection frequency
- The type of vehicles used for collection and short distance transport
- Number of collection shifts per day.

Estimation of the collection costs should consider the following parameters:

- Waste quantities collected
- Container volume and type
- Requirements for container sites or slabs, if applicable

Box 1: Main mistakes when planning collection systems with bearing on costs

- The full collection costs are not considered, for example, when part of the collection equipment is provided as a grant.
- The collection costs are not separated from other waste management or public utility costs, for example, street cleaning.
- The number and qualification of appointed personnel does not correspond to the equipment used.
- A much larger number of containers are installed than actually needed.
- The collection equipment is not efficiently used, for example, the vehicles operate less than 80 percent of the collection time.
- Maintenance and repair costs are underestimated or insufficient funding is allocated for maintenance, for example, replacement of tires, broken container wheels or lids, problems with vehicle compaction systems.
- Shorter lifetime of containers and vehicles are used because of low-quality equipment or lack of maintenance due to which the containers or vehicles are not operational for longer periods or have to be replaced earlier than planned.
- Daily routines are not defined and/or service performance indicators are not established.
- Lower collection efficiency are observed than initially planned, for example, inappropriate container placement necessitating additional maneuvering of collection vehicle, cleaning the areas around container sites, and manual loading of waste placed outside waste containers.
- The containers installed are not appropriate for the type of vehicles used and vice versa.
- The service providers have no experience or capacity to properly operate and/or maintain the new equipment, which could result in damages.

Box 2: Waste containers versus bin free systems

Although waste collection systems in high-income countries (HICs) are almost exclusively conducted with waste containers (bins), considered a best practice, containers/bins are not available in many locations in LICs and MICs. This could be due to financial limitations or a local government policy (for example, 'Bin Free City' policy common in India and Thailand). In these cases, the waste is either taken straight to the collection truck by waste generators or waste is accumulated in uncontained piles awaiting bulk collection. There are certain implications of non-containment systems including waste scattering due to wind, rain, animals, and rain infiltration as well as increased weight of waste, health and safety risks of workers and the public, and so forth. In addition, there is potentially lower loading efficiency due to time taken to load the waste manually or mechanically from the ground into trucks. While this guidance recommends that the waste is contained at the point of collection, it should be acknowledged that this is not always the case. Therefore, specific conditions and collection time for uncontained locations must be adjusted for the collection method employed locally.

- Asset lives for different asset categories. The usual lifetime of containers is 7 years and of vehicles is 10 years
- Waste density in containers and compaction vehicles
- Collection frequency
- Average proportion of bin utilization/degree of container filling
- Irregularities in waste generation, usually presented as 'irregularity coefficient' calculated as a ration between the maximum and average daily quantity of waste collected
- Time taken to lift one container
- Payload of collection trucks and utilization rate
- Number and duration of working shifts
- Personnel working days and effective working hours per day
- Number of loaders per collection vehicle
- Collection working days
- Distance (on suitable route for type and gross [full] weight of vehicle) to landfill or treatment facility, average speed of travel (accounting for traffic congestion), and time spent for unloading at the site
- Fuel consumption for the types of collection trucks to be used.

Developing costs estimates for municipal waste collection system requires determining investment and operating costs for each element of the selected system.

The investment costs of municipal waste collection relate to

- Supply and replacement of containers and bins;
- Costs for construction of container sites or slabs;[14]
- Purchasing costs for waste collection vehicles;
- Costs for other vehicles, for example, container cleaning vehicles, vehicles for supervisors; and
- Costs for acquisition of other assets, not directly related to municipal waste collection (garage for collection vehicle, offices, and so on).[15]

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[14] Not considered in the present document. The construction of container sites is usually not included in waste collection costs and tariffs and is typically financed by other municipal sources.

[15] In case of more general analysis during preliminary planning stages, these costs are usually not con-

The following operating costs are incurred for municipal waste collection:

- Personnel costs, including social and health insurances, provision of personnel protective equipment
- Maintenance costs for waste collection containers and vehicles
- Fuel costs
- Costs for other consumables such as lubricants and tires
- Public awareness costs
- Insurance costs for personnel, containers,[16] and vehicles
- Administrative costs.

The calculation of investment and operating costs over the project planning period allows the determination of unit costs such as costs per tonne, person, container lifted, and household—also used as comparison or benchmark indicators.

The costs for collecting residual waste exhibit some variation depending on the selected technical solutions and local conditions in the country/region. The most typical are as follows:

- Variations in the typical situation in respect of the number of collection points passed per unit of time (the higher this is, the lower the cost—this is not simply an issue of population density, though this has an effect, but is also affected by factors such as traffic).
- The nature of municipal waste fees or taxes and the responsibility to provide required containers, bins, or other receptacles used (in some systems, residents purchase bags/bins, in others, these are provided my municipality or operator of services and the respective costs included in the municipal waste tariffs).
- Variation in the quantity of residual waste collected per collection point (the lower the collection, the higher the per tonne cost), which, is affected by
  - The rate of source separation (effective source separation reduces the residual waste set out);
  - The nature of containers used for collection; and
  - What householders are allowed to put in the container for collection (for example, whether garden waste is excluded).
- The vehicles used and their maximum payload (as long as vehicles are not completing rounds half empty—larger vehicles can reduce costs);
- Labor costs (these vary with the number of operatives, which is affected by the nature of the area where collection takes place, and with unit labor costs in country);
- The frequency of collection, related to the nature of the housing stock, the collection mechanism, the climate, and most significantly, the presence or absence of food waste/biowaste separate collections; and
- The sophistication of the collection equipment (for example, are vehicles equipped with on-vehicle weighing systems or other computational equipment designed to record emptyings of containers).

This guideline acknowledges the different collection models operating globally, particularly in LICs and MICs. It is relatively common in many large urban cities to have a

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sidered as separate investment but as overheads over direct collection costs on an annual basis.

[16] Containers' insurance is not a common practice.

primary collection service (from door-to-community waste container or small transfer station) that is operated by local entities separate from the municipal SWM service. This is often financed through fees levied directly to the waste generator at the point of collection (for example, household door) or through community collected payments given to local youth groups or entrepreneurs that deliver the service. The waste is then taken to community-level collection points (secondary collection points) that are planned and operated by the city administration. The present document, while acknowledging that primary collection service is critical to the full waste management service, is focused on municipality/local administration delivered service where the service starts from the community bin/secondary waste collection point level.

3.1.1 Examples for waste collection costs estimates

Table 3[17] presents a summary of costs for waste collection using standard 1.1 m^3 waste containers with wheels in settlement with 100,000 residents.

Table 3: Waste collection with 1.1 m^3 standard euro containers

Parameter	Unit	Urban	Rural	Total
		Quantity		
Residents	Residents	70,000	30,000	100,000
Waste collected per capita including commercial waste	kg/capita/year	379.8	339.8	367.8
Collection frequency	Times/year	365	104	
Average degree of container filling	%	85	85	
Irregularity coefficient[18]	Value	1.3	1.3	
Average volume per container lifted	m^3/container	0.7	0.7	
Containers needed	Pcs.	633	852	1,485
New containers to be purchased, including reserve	Number	665	895	1,559
Investment for new containers	$ thousand	426.7	574.3	1,001.0
Depreciation containers	$ thousand	61.0	82.0	143.0
Average distance to disposal site	km	15	30	
Average speed when travelling[19]	km/h	35	35	
Time for loading one container[20]	Minutes/container	1.50	1.50	
Loading efficiency/hour	Tonnes/hour	4.6	4.6	
Collection trucks required (including reserve)	Number	6.3	3.4	9.7
Collection trucks in operation	Number	5.4	2.9	8.3
New trucks required including reserve	Number	7.0	4.00	11.0
New investment for collection trucks	$ thousand	898.8	513.6	1,412.4
Depreciation vehicles	$ thousand	93.7	53.3	147.0

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[17] Calculations done under following assumptions: (i) For waste collection in 1 shift and 7 days per week in urban areas and 5 days per week in rural areas. (ii) Density of waste in containers 0.16 tonnes/m^3, container volume 1.1 m^3, vehicle volume 16 m^3 and vehicle average payload 8 tonnes, utilization 85%.

[18] Ratio between the maxim and average daily quantities.

[19] Average speed when travelling refers to the time for travelling to/from garaging location and disposal site (versus loading route).

[20] Time for loading one container includes maneuvering and lifting containers as well as time to travel between containers. Where waste is not contained in containers, this includes the time to physically load waste into trucks; wait for loading equipment, crews, or waste generators to come to the truck; and the rest time on route where required.

Table 3: Waste collection with 1.1 m³ standard euro containers (cont.)

		Urban	Rural	Total
Parameter	**Unit**	**Quantity**		
O&M costs	$ thousand	563.6	306.6	870.1
Staff costs	$ thousand	182.9	67.1	249.9
Fuel	$ thousand	115.5	66.3	181.9
Other consumable	$ thousand	2.3	1.3	3.6
Maintenance costs	$ thousand	73.6	55.2	128.8
Administration	$ thousand	37.4	19.0	56.4
Unscheduled services	$ thousand	56.6	34.4	91.1
Overheads	$ thousand	46.8	24.3	71.2
Insurance	$ thousand	48.4	38.9	87.1
Unit operating cost	$/tonne	21.2	30.1	23.7
Unit depreciation cost	$/tonne	5.8	13.3	7.9
Unit annual cost	$/tonne	27.0	43.3	31.5
Price per lifting of 1 container	$/container	3.1	5.0	
Price per resident	$/resident/year	10.3	14.7	11.6

In case 1.1. m³ containers in the above example are replaced with 240 liter plastic bins with wheels provided to individual houses in rural areas (30,000 residents), collection costs will change as presented in Table 4 (assumed waste collection organized in one shift, 5 days per week). It can be observed that higher collection efficiency is achieved with fewer and larger bins requiring less stops for collection and loading and consequently two trips per shift versus longer times required to stop and load numerous 240 liter bins allowing only one trip per shift.

Table 4: Comparison of waste collection with 1.1 m³ standard euro containers and individual 240 liter plastic bins

Parameter	Unit	1.1 m³ containers with wheels	240 liter bins with wheels
Residents	Residents	30,000	30,000
Waste collected per capita	kg/capita/year	339.8	339.8
Container volume	m³/container	1.1	0.2
Collection frequency	Times per year	104	52
Average degree of container filling	%	85	85
Irregularity coefficient	Value	1.3	1.3
Average volume per container lifted	m³/container	0.7	0.1
Average lifted quantity	Tonnes/container	0.1	0.0
Average number of households per container	Number	11.7	1.0
Containers/bins needed	Pcs.	852	10,000
New containers to be purchased	Number	895	10,500
Investment for new containers	$ thousand	574.3	674.1
Depreciation containers/bins	$ thousand	82.0	96.3

Table 4: Comparison of waste collection with 1.1 m^3 standard euro containers and individual 240 liter plastic bins (cont.)

Parameter	Unit	1.1 m^3 containers with wheels	240 liter bins with wheels
Average distance to disposal site	km	30	30
Average speed when travelling	km/h	35	35
Time for loading one container	Minutes/container	1.5	0.8
Loading efficiency/hour	Tonnes/hour	4.6	1.6
Average trips per day	Trips/day	2	1
Collection trucks required (including reserve)	Number	3.4	6.8
Collection trucks running	Number	2.9	5.8
New trucks required	Number	4.0	7.0
New investment for collection trucks	$ thousand	504.0	918.0
Depreciation vehicles	$ thousand	53.3	91.8
O&M costs	$ thousand	306.6	450.7
Number of employees	Number	12.0	23.0
Staff costs	$ thousand	67.1	128.6
Fuel costs	$ thousand	66.3	71.9
Other consumable	$ thousand	1.3	1.4
Maintenance costs	$ thousand	55.2	79.0
Administration	$ thousand	19.0	28.1
Unscheduled services	$ thousand	34.4	49.7
Overheads	$ thousand	24.3	35.9
Insurance	$ thousand	38.9	56.2
Unit operating cost	$/tonne	30.1	44.2
Unit depreciation	$/tonne	13.3	18.5
Unit annual cost	$/tonne	43.3	62.7
Price per lifting of 1 container/bin	$/container	5.0	1.2
Price per resident	$/resident/year	14.7	21.3

The costs per tonne of waste collected are usually higher in case of using individual bins compared to bring system with larger volume containers. The reason is lower loading efficiency, that is, less quantity is loaded in the same time and it takes more time to fill the collection vehicle. Using individual bins is sometimes also difficult due to limited access and narrow roads to served areas that also require using small volume collection vehicles.

On the other hand, individual bins have advantages of allowing clear cost allocation to household and applying volume or weight-based tariffs for services. The individual bins are also more convenient if separate collection and composting programs are applied in parallel to residual waste collection. The reason is that the amount of mixed waste that households could discard is limited by the bin volume and collection frequency, which is not the case for large volume containers placed in public sites serving many anonymous users in the area.

There are many different collection systems implemented using different containers and collection vehicle types. Few examples about the number of required containers and vehicles for different types of collection schemes in an urban area with 70,000 residents are presented in Table 5.

Table 5: Comparison of waste collection schemes

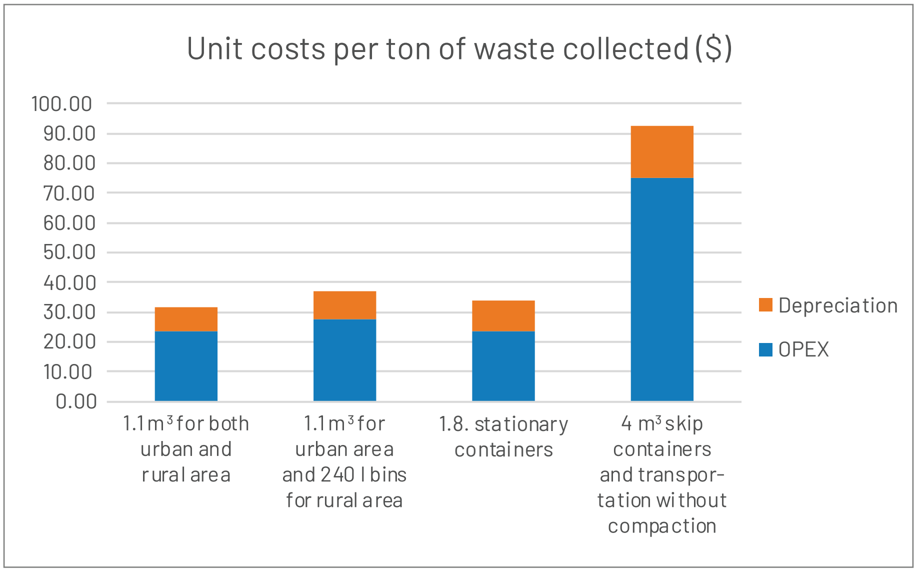
Parameter	Unit	1.1 m^3 containers with wheels	1.8 m^3 stationary containers	4 m^3 skip containers
Residents	Residents	70,000	70,000	70,000
Waste collected per capita	kg/capita/year	379.8	379.8	379.8
Waste quantity	Tonnes	26,587	26,587	26,587
Waste density	Tonnes/m^3 in container	0.16	0.16	0.24
Container volume	m^3/container	1.1	1.8	4.0
Collection frequency	Times per year	365	365	365
Average degree of container filling	%	85	85	100
Irregularity coefficient	Value	1.3	1.3	1.1
Average volume per container lifted	m^3/container	0.7	1.2	3.3
Average lifted quantity	Tonnes/container	0.1	0.2	0.7
Average number of households per container	Number	36.9	60.3	208.3
Containers needed	Pcs.	633	387	112
New containers to be purchased	Number	665	406	118
Investment for new containers	$ thousand	426.7	413.1	209.0
Depreciation containers	$ thousand	61.0	59.0	29.9
Collection vehicle type		16 m^3 rear-end loading compactor	21 m^3 side loading compactor	Skipper truck
Average pay load	Tonnes	8	10.5	0.8
Utilization	%	85	85	100
Average distance to disposal site	km	15.0	15.0	15.0
Average speed when travelling	km/h	35.0	35.0	35.0
Time for loading one container	Minutes/container	1.5	3.0	8.0
Loading efficiency/hour	Tonnes/hour	4.6	3.8	n.a
Average trips per day	Trips/day	2.0	2.0	5.0
Average load collectable/day	Tonnes/day	13.6	17.9	3.3
Collection trucks required (including reserve)	Number	6.3	4.8	21.9
Collection trucks running	Number	5.4	4.1	18.6
New trucks to be purchased	Number	7.0	5.0	22.0
New investment for collection trucks	$ thousand	898.8	1,078.6	1,920.6
Depreciation vehicles	$ thousand	92.0	109.6	192.1
O&M costs	$ thousand	563.6	477.8	1,329.5
Number of employees	Number	32	11	40

Table 5: Comparison of waste collection schemes (cont.)

Parameter	Unit	1.1 m^3 containers with wheels	1.8 m^3 stationary containers	4 m^3 skip containers
Staff costs	$ thousand	182.9	82.9	309.7
Fuel costs	$ thousand	115.5	138.7	586.4
Other consumable	$ thousand	2.3	2.8	11.7
Maintenance costs	$ thousand	73.6	79.7	181.2
Administration	$ thousand	37.4	30.4	54.5
Unscheduled services	$ thousand	56.6	50.5	68.3
Profit	$ thousand	46.8	38.5	60.6
Insurance	$ thousand	48.4	54.4	57.2
Unit operating cost	$/tonne	21.2	18.0	50.0
Unit depreciation	$/tonne	5.8	6.4	8.4
Unit annual cost	$/tonne	27.0	24.4	58.4
Price per lifting of 1 container	$/container	3.1	4.6	45.8
Price per resident	$/resident/year	10.3	9.3	22.2

Figure 2 presents costs per tonne of waste collected for the different collection systems presented above, for a service area of 100,000 residents.

Figure 2: Comparison of waste collection costs for different systems



The above comparison shows that waste collection without compaction has considerably higher costs per tonne compared to other collection schemes considered.

Within the assumptions made, the waste collections using standard 1.1 m^3 containers with wheels and large volume stationary containers have comparable costs per tonne despite differences in investment requirements, labor involved, and operating costs. It should be noted, however, that a variety of local factors such as social and cultural aspects can also play a role in waste management system design and should be considered carefully according to local conditions and needs.

The above examples are for illustrative purposes only. The actual collection systems in large agglomerations usually combine different collection schemes and logistic arrangements. Significant price differences could also occur depending on equipment used, labor costs, and other specific local conditions.

3.1.2 Impact of distance to disposal site on waste collection costs

The waste collection costs increase with the increase in distance to the final waste management site.

Figure 3 shows the impact of distance on the collection costs per tonne of waste. The calculations are done for settlement with 70,000 residents using 1.1 m^3 containers with wheels and 16 m^3 rear-end collection vehicles with compaction. The waste collection is organized daily in one shift.

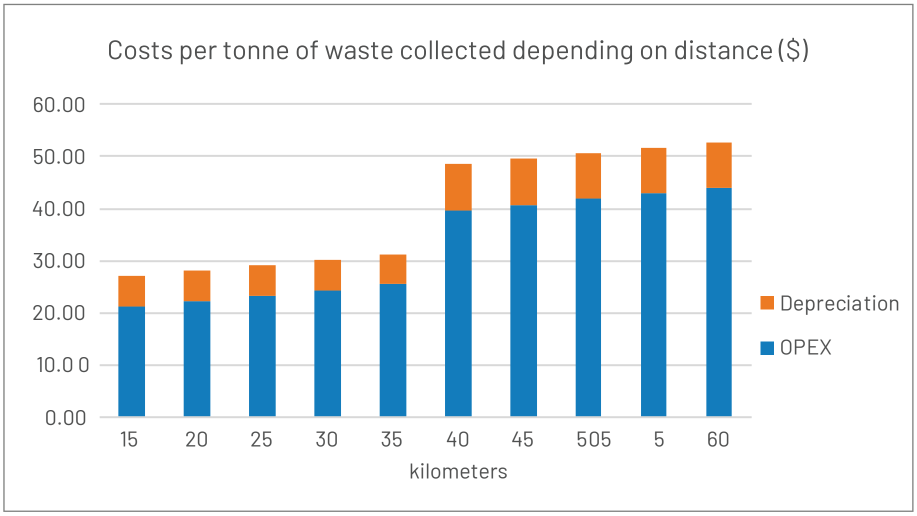


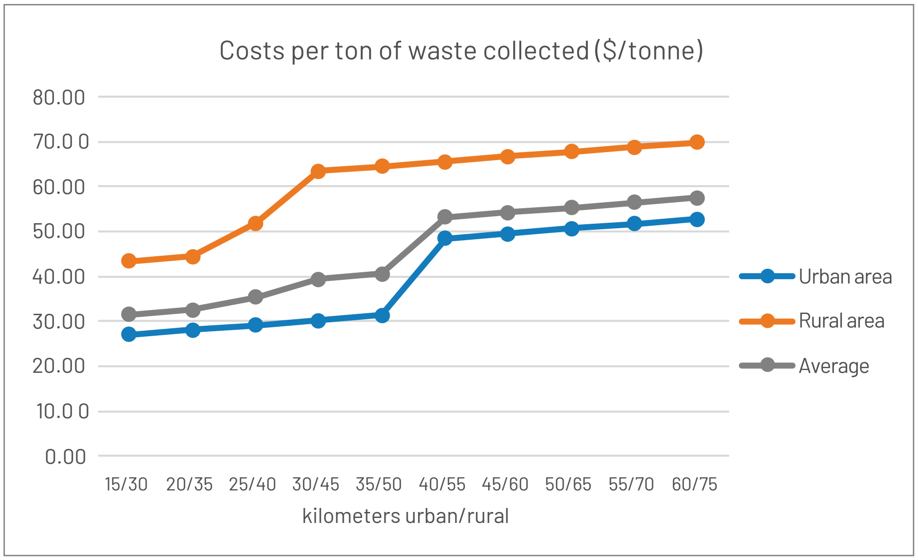
Figure 3: Impact of distance on collection cost per tonne in urban areas

As presented in Figure 3, there is a small linear increase in the collection costs with the increase in distance to disposal site from 15 km to 35 km followed by a rapid increase when distance reaches 40 km which is again followed by linear increase. This is due to two factors that need to be considered. The first one is fuel consumption that increases with travelling distance. The second factor is that the more time the vehicle spends travelling to the disposal site, less time it has for waste collection within the working shift. In the example above, the waste collection vehicle is capable of covering two routes per shift for distances of up to 40 km to disposal site . With further increase in distance, the vehicle is capable of completing only one full route which is the reason for the rapid cost increase.

In case only full routes are considered, the transportation of waste to 40 km will mean that the truck is not fully utilized and effectively works less than 5 hours per shift. Such situations should be avoided in practice and alternative options to optimize collection costs should be considered. Depending on local conditions, there could be, for instance, changes in route planning, changes in vehicle volume and/or characteristics, an increase in the number of working shifts, a reduction in the number of containers served per route (if relatively small reduction of utilized payload is required), or consideration of a transfer station if quantities justify its use. Though not optimal, some operators are also considering half route operation in which cases the collection vehicle would cover only part of its assigned route during the working shift and will stay overnight in the garage half full without going to landfill. Nevertheless, it should be noted that such practice increases risk of fire, can lead to more rapid corrosion of compaction unit resulting in lower service life, and generally increases insurance premiums.

The collection costs under different collection systems change differently with increase in transportation distances due to their different loading efficiencies. The example shown in Table 3 for waste collection in urban area for 70,000 residents using 1.1 m^3 containers and in Table 4 for waste collection in rural area with 30,000 residents using 240 liter bins could be used again to show how collection costs are changing with increase of transportation distance for a municipality with 100,000 residents.

Figure 4: Impact of distance on collection costs per tonne in urban and rural areas



It can be seen that initially the collection costs increase more significantly in rural areas where collection is provided with 240 liter bins and average transportation distances are higher.

3.1.3 Impact of container loading time on collection costs

Loading efficiency is a key parameter affecting costs of the collection system. It is usually presented in tonnes per hour but a simple estimate is the time for loading one container.

Different container types and vehicles have different loading times that could be found in their technical specifications. Actual time for container loading includes the time for container manipulations and time for travelling to the next container.

The actual loading time for the existing collection system can be easily obtained through dividing the effective vehicle operating time excluding time for travelling to/from disposal site by the number of containers served for the respective collection route. On this basis, the average loading time for the entire collection system can be obtained by combining data from all collection routes.

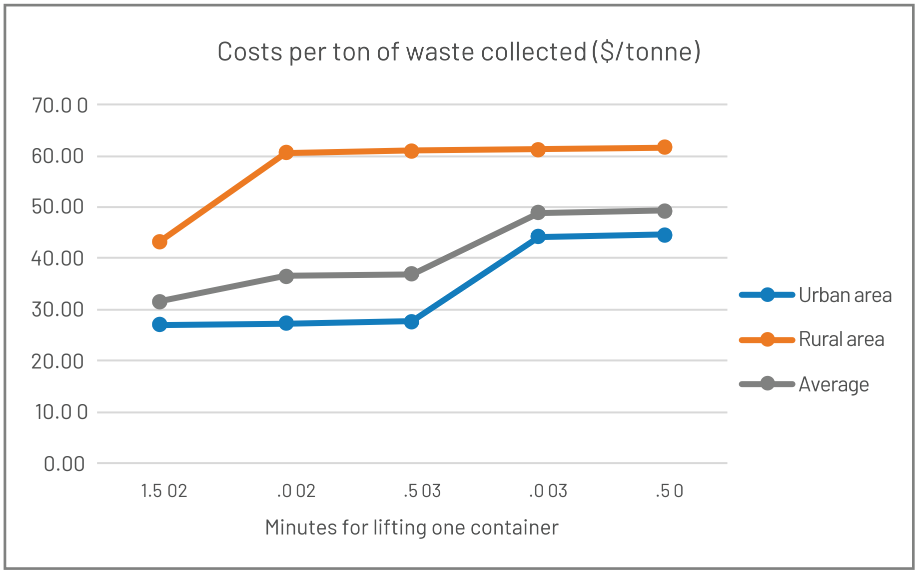
Considering that the maximum distance from the building entrance to the container site is accepted to not exceed 100 m, the maximum distance between two container sites should not exceed 200 m. Considering that time for lifting one container is below 25 seconds, the optimal time for loading 1.1 m^3 container in urban area is supposed to be below 1.5 minute. This includes time for lifting the container and moving to the next container site.

The example highlights one of many reasons to have a containerized collection system as the time required to collect waste from an uncontained waste collection point far exceeds the time of lifting and emptying a container and therefore greatly affects overall service efficiency and operational costs.

The container placement is the main factor affecting the loading time. When containers are installed along the main roads, they are easily accessible by the collection vehicles. Placement of containers in backyards, in special building premises, or in other areas with difficult access increases the vehicle maneuvering time.

Figure 5 presents the unit costs per tonne and costs per lifting of one container with different loading times in a service area with 100,000 residents. The estimates are calculated for average transport distance to disposal site of 15 km for urban areas and 30 km for rural areas.

Figure 5: Impact of container loading time on unit costs



The above examples refer to containerized collection. Often in LICs and MICs, waste is discarded by residents directly on designated site or land and then manually or mechanically loaded to collection vehicle and transported to disposal site with or without compaction. Such practice is usually justified in cases when there are limited available funds for purchasing of containers and more expensive collection vehicles. In addition to the potential issues related to contamination around the site, such practice usually results in higher collection costs compared to containerized collection systems due to lower loading efficiency. This highlights the argument to have a containerized collection system since time required to collect waste from an uncontained collection point far exceeds the time of lifting and emptying a container and therefore affects the overall service efficiency and operational costs.

3.1.4 Impact of collection frequency on collection costs

The collection frequency also has a significant impact on costs. More containers are needed to collect the same volume of waste if the frequency of collection is lower.

It is obvious that increasing collection frequency without adjusting other conditions will reduce collection costs. Using a lower number of containers could also create difficulties due to fluctuations in waste quantities over time. The fewer containers that are used, the higher the likelihood of waste overflowing out of containers.

More containers used also means more space occupied. Such free space is usually not easily available. Installing additional containers is also reducing parking space available in the same area. Conversely, reducing number of containers used increases distance between containers, and service users have to walk further to discard their waste.

Table 6 presents a comparison of daily collection, every second day collection, and twice per week collection. The estimates are calculated for an urban area with 70,000 residents.

Table 6: Impact of collection frequency on waste collection costs

Parameter	Unit	Every day (7/7)	Every second day (2/7)	Twice per week (2/7)
Containers needed	Pcs.	633	1,270	2,222
Reserve for maintenance	%	5	5	5
New containers	Number	665	1,334	2,333
Unit operating cost	$/tonne	21.2	22.9	25.4
Unit depreciation	$/tonne	5.8	8.1	11.6
Unit annual costs	$/tonne	27.0	31.0	36.9
Price per lifting of 1 container	$/container	3.1	3.6	4.3
Price per resident	$/resident/year	10.3	11.8	14.0

The provided examples for bring waste collection systems using 1.1 m^3 containers with wheels show that costs increase with the reduction of collection frequency. The simple explanation is that a larger number of containers and consequently higher investment costs are needed to collect the same volumes less frequently.
This argument should be interpreted with some caution because quite often limitations on collection frequency apply due to specific local conditions. This example serves to highlight the interconnection of system elements and sanitary norms. It is important to design a service that ensures the container and vehicles are sized appropriately to mitigate excessive unit (container and vehicle) numbers, and merely reducing collection frequency may not achieve cost savings. In case of bring collection systems, it is practical to collect waste more often in areas with multistorey buildings and usually this happens every day or even twice per day in densely populated areas or central parts of the cities where large volumes of waste are generated and possible locations where container sites are limited. In less populated areas and areas with family houses, lower collection frequencies apply, which also helps reduce the walking distances between premises and containers.

In curbside collection systems where individual containers are provided to the house or building, the collection frequency is usually predefined. For example, plastic bins with two wheels provided to family houses are usually collected once per two weeks or once per week and the container size and number is selected accordingly, considering the waste quantities collected.

3.1.5 Impact of vehicle size on collection costs

Vehicle size has a significant impact on collection costs.

Using larger volume collection vehicles with compaction is more cost-effective because the vehicle is spending more time to load waste and less time to travel to/from disposal site for the same waste quantities. In the same way, using small volume collection vehicles for transportation to large distances is not a cost-effective solution.

However, using large volume collection vehicles is not always possible due to narrow streets, weight limits on roads and bridges, and difficult access in some areas.

It is also important that each collection vehicle completes one or several full routes within the working shift. For example, if the time for loading vehicle and travelling to the disposal site is 5 hours, it is obvious that there is not enough time left for completion of a second trip. If no second trip is made, such vehicle and its crew is not effectively utilized. Even if a second trip is made, the vehicle will travel half empty which should be avoided. The possible solution in this case is to consider whether using smaller vehicle capable of covering two trips per shift will be appropriate, assuming that smaller vehicles have lower investment and operating costs compared to larger vehicles. Alternatively, the working hours of the larger vehicle could be extended and prolonged shift duration could be introduced (for example, 12 hours) or a second shift applied.

3.1.6 Impact of working shifts on collection costs

Transfer from one working shift to two working shifts reduces the number of vehicles used.

Work in two and even three shifts is a common practice in large cities and rarely applied in rural areas.

Table 7 exemplifies the impact of the number of shifts. The estimates are made for a service area with 70,000 residents, average transport distance of 15 km to disposal site, and daily collection.

Table 7: Impact of number of shifts on waste collection costs

Parameter	Unit	1 shift	2 shifts
Collection trucks required (including reserve)	Number	6.3	2.5
Collection trucks running	Number	5.4	2.1
New trucks required	Number	7.0	3.0
New trucks to be purchased	Number	7.0	3.0
New investment for collection trucks	$ thousand	898.8	385.2
Unit operating cost	$/tonne	21.2	15.9
Unit depreciation	$/tonne	5.8	3.8
Unit annual costs	$/tonne	27.0	19.7
Price per lifting of 1 container	$/container	3.1	2.3
Price per resident	$/resident/year	10.3	7.5

Applying a second shift could have other benefits such as avoiding waste collection during hours with high traffic.

Box 3: Tips for waste collection

- Knowing the actual waste quantities is crucial for understanding the real costs of collection systems.
- Using generation norms presented in volume per capita should be avoided when planning the collection system. Such volume figures cannot be checked and confirmed.
- Low initial investment costs do not mean lowest overall costs over the implementation period.
- The number of containers and container sites used should ideally be selected in a way that the maximum walking distance from the entrance of a living premise to the container site does not exceed 100 m.
- Costs per tonne and costs per resident serve as key performance indicators (KPIs) and could be compared with other cities.
- In case costs per tonne for waste collection and transportation exceed $50/tonne, there is a possibility for cost optimization.
- If municipal waste collection costs are below $20/tonne, it should be checked that all cost components have been considered.
- Transportation of uncompacted waste should be avoided.
- Collection with small volume collection vehicles in case of significant transportation distances should be avoided.
- Vehicle availability and utilization close to 90% should be the goal.

3.2 Municipal waste transfer

Box 4: Main mistakes when planning municipal waste transfer stations

- Transfer stations are constructed without detailed cost analysis and proper justification.
- The transfer station site is not properly selected due to no or limited alternatives considered during the feasibility stage or incomplete selection criteria used.
- The transfer technology and transportation system are inappropriate for the selected location, waste quantities, and road conditions or lack optimized compatibility with primary collection vehicles.
- Service contracts for transfer station operation and equipment maintenance are inappropriate, for example, the transfer costs are not accounted separately from waste collection.

- Transfer stations are justified when the cost to transport waste directly from the point of generation to a treatment/disposal site is greater than the cost to transport the waste from the source of generation to a point where the waste is transferred onto a larger container or vehicle and then transported to the final treatment site or landfill. The economical expediency of transfer stations is influenced by several factors:
- Distances
- Quantities of waste (capacity of transfer station)
- Road conditions and topography
- Low density of population in the service areas
- Technology of transfer.

Transfer stations can be basically divided into two types:

- Transfer of municipal waste by using a compaction system
- Transfer of municipal waste using containers or semi-trailers without compaction.

The transfer stations can be constructed

- As stations with direct unloading into the transfer hopper or containers; or
- With an interim storage area, which allows buffering the waste during peak hours.

The transfer stations may be with roofed transfer area, to allow proper working conditions in case of rain, or/and fully housed and equipped with ventilation and odor treatment. Nowadays, open air plants are not considered an optimal solution due to issues with odors and rainwater.

Transfer stations without compaction are used when distances are not large, whereby the higher investment costs of transfer stations with compaction cannot be justified.

With larger distances, the operational costs of transfer stations without compaction become higher compared to those of transfer stations with compaction. The choice of transfer station is in fact a trade-off of investment and operating cost.

The capacity of a transfer station has an impact on the unit costs of transfer. As with most plants, economy of scale is also an important issue for the transfer station.

The location of the transfer station should be as close as possible to its CA to minimize the distance that the primary waste collection vehicles must travel to deliver their municipal waste. The shorter the distance to the transfer station, the more time the primary collection vehicles will have to conduct another waste collection trip or for longer collection if not fully loaded.

Transfer stations without compaction

For small municipal waste quantities of up to 100 tonnes/day and transportation distances of 50–60 km, simple transfer stations with open containers are usually the more economical solution. The waste is directly tipped into a container or semi-trailer and is then hauled to the treatment or disposal plant. There are several types of semi-trailer technologies, such as tippers or semi-trailers with walking floor. Such transfer stations usually have multiple tipping places for several roll-off containers or semi-trailers.

Often the municipal waste is slightly compacted by a wheeled loader or rolling compactor before hauling. Depending on the composition of the wastes and whether the waste was already compacted in a waste collection vehicle or whether it was delivered loose on open trucks or by companies, the density in these containers can vary, typically between 200 kg/m^3 and 350 kg/m^3.

The municipal waste can also be transported by truck trailers, transporting two containers of 40 m^3 each or about 16 to 20 tonnes in total, or walking floor semi-trailers with up to 100 m^3, transporting 18 to 22 tonnes.

Transfer stations with compaction

The purpose of transfer stations with compaction is to increase the density of the waste and thus the quantities of waste to be transported in one run. Such transfer stations are equipped with a ramp having a discharging point, reception bunker (of about 45 m^3), compacting device, large transportable containers (often between 27 m^3 and 32 m^3), railing system for shifting the containers, and vehicles for long-distance transportation.

Equipment of such transfer stations is designed to minimize the loading time from collecting trucks and the compacting time for the waste. An automatic railing system for shifting the containers is also installed to reduce the operation time. While a long-distance transport vehicle is being loaded with a full container, another container may receive new wastes.

In a compaction transfer station, the municipal waste is compacted to a density of up to 600 kg/m^3. There are compaction systems that can compact up to 70 tonnes/hour of waste, mainly limited by the necessary exchange of compaction containers. Such compaction containers might also be mounted on semi-trailers.

To always be sure that at least one compactor is operating, during periods of major overhauls of a compactor, usually a transfer station needs to be equipped with at least two compactors. Besides the much more complicated mechanical equipment for compacting, the need of at least two compactors results in comparatively high costs when small waste quantities are being transferred. Additionally for small quantities, two compactors cause high overcapacities.

The static compacting device can be substituted with large self-compacting transportable containers, between 25 m^3 and 32 m^3, that are able to store between 15 tonnes and 19 tonnes.

The transfer stations with compaction are usually used for large quantities and long transfer distances. However, given the maximum weight conditions on road of 40 tonnes, the maximum payload usually is in the range of 22–24 tonnes, that is, practically the same weight as used for transfer without compaction.

Waste transfer using satellite collection vehicles

Over the last decades, several manufacturers of collection vehicles have developed solutions allowing waste from a small volume vehicle (up to 8–10 m^3) to be reloaded directly to a large rear-end loading collection vehicle with compaction and capacity exceeding 21 m^3. In this case there is no need for a special transfer station and reloading is conducted directly on the road. Such solution allows the small collection vehicle(s) to operate in the areas with narrow streets where the access of the larger vehicle is not possible. In addition to the waste reloaded from the small vehicles, the large vehicle could also serve and collect waste from containers installed around the main roads in the service area. Solutions also exist for reloading waste collected from small vehicle into roll-on container with compaction or large volume semi-trailer with compaction.[21] A similar system is typical in LICs and MICs at the interface between community-operated primary waste collection services using hand carts, motor tricycles, and small vans and the secondary collection or transfer to larger haulage vehicles operated by the municipal authority.

If we consider again the example provided in Figure 4 for organizing municipal waste collection in a settlement with 100,000 residents and assuming average transportation distance of 50 km to disposal site, the following three alternatives are compared:

- Direct transportation of waste
- Establishment of transfer station with compaction using stationary compactor and 30 m^3 hooklift containers
- Establishment of transfer station without compaction.

The comparison of investment and operating costs and unit costs per tonne of waste collected is presented in Tables 8 and 9, where the annual operating costs are presented for the first year of operation. Variations between operating costs for different years exist due to different waste quantities collected. The capacity of the transfer station in the given example is 40,000 tonnes/year with or without compaction.

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[21] Electricity supply is needed on site where press container or trailer is installed.

Table 8: Comparison of investment and operating costs for direct transportation of waste and using transfer station

Parameter	Unit	Direct transport	Transfer without compaction	Transfer with compaction
Residual waste collection				
New containers to be purchased	Pcs.	1,559	1,559	1,559
Investment costs of containers	$ thousand	1,001	1,001	1,001
Number of waste collection vehicles required	Pcs.	20	9	9
Investment costs of collection vehicles	$ thousand	2,568	1,156	1,156
Waste collection operating costs	$ thousand	1,629	719	719
Transfer and transportation of residual waste				
Investment costs for transfer station	$ thousand	–	699	1,346
Number of transportation vehicles required	Pcs.	–	8	4
Investment for transportation vehicles	$ thousand		873	437
Waste transfer and transportation operating costs	$ thousand		758	606
Cumulative collection and transfer costs				
Investment costs	$ thousand	3,569	3,729	3,940
Operating costs	$ thousand	1,629	1,477	1,325

The above cost estimates show that a transfer station with compaction has the highest total investment costs for waste collection and transfer but lower operating costs.

Table 9 compares the unit costs calculated as discounted unit cost (DUC)/AIC for a period of 10 years.

Table 9: Comparison of unit costs for direct transportation and using transfer station with or without compaction ($/tonne)

Parameter	Direct transport	Transfer without compaction	Transfer with compaction
Residual waste collection			
Investment costs	13.5	8.4	8.4
Operating costs	44.2	19.4	19.4
Total residual collection costs	57.8	27.7	27.7
Transfer and transportation of residual waste			
Investment costs	–	5.3	6.2
Operating costs	–	20.4	16.1
Total waste transfer costs	–	25.6	22.3
Total collection and transfer costs			
Investment costs	13.5	13.6	14.5
Operating costs	44.2	39.7	35.5
Total collection and transfer costs	57.8	53.3	50.0

The provided example shows that construction of a transfer station with compaction is justified for the specific case considered. The additional investments required for the construction of a transfer station are partly absorbed due to the smaller number of collection vehicles required compared with the case of direct transportation. In the example considered, the construction of a transfer station leads to reduced operating costs.

The above example is relevant for the case when relatively small quantities of waste collected from one or several municipalities have to be transferred and transported to a treatment or disposal facility situated near larger settlement in the same planning area.

The use of a transfer station can also be justified in large population agglomerations. In this case, some districts could be situated away from the disposal facility and due to the large waste quantities, the transfer station could provide flexibility in the selection of collection vehicles and help reduce waste collection and transportation costs. A sample cost estimate for a transfer station serving 1,000,000 residents and with capacity of 400,000 tonnes per year is shown in Table 10, where the operating costs were estimated for average waste quantity of 370,000 tonnes/year and DUCs (AIC) are calculated for 5 percent discount rate and 12-year period following the initial investment.

Table 10: Summary costs data for a transfer station with larger capacity

Parameter	Unit	Value
Investment costs for transfer station site, including	$ thousand	6,375
Land acquisition	$ thousand	–
Civil works	$ thousand	1,518
Machinery	$ thousand	2,432
Vehicles, mobile equipment	$ thousand	1,723
Engineering, commissioning, contingencies	$ thousand	701
Depreciation costs for transfer station	$ thousand/year	536
Unit depreciation costs of waste transfer	$/tonne	1.45
Transportation distance	km	30
Operation shifts	Number	2
Number of transportation vehicles required	Pcs.	8
Investment for transportation vehicles	$ thousand	1,746
Depreciation costs of transportation vehicles	$ thousand/year	175
Unit depreciation costs of transportation vehicles	$/tonne	0.5
Waste transfer and transportation operating costs	$ thousand	3,289
Unit operating costs	$/tonne	8.9
Annual costs	$ thousand	4,000
Unit annual costs	$/tonne	10.81
Discounted investment unit costs of waste transfer	$/tonne	2.6
Discounted operating unit costs of waste transfer	$/tonne	8.9
DUC waste transfer	$/tonne	11.5

Box 5: Tips for waste transfer

- The major argument for using a transfer station is the reduction of transport costs compared to direct transportation of waste. Another argument for using transfer stations could be to balance the costs in regional waste management system. In case of significant differences of collection costs between several municipalities served by common regional landfill or treatment facility, a possible way to equalize costs is to establish a system of transfer stations such that each entity pays broadly the same cost per tonne of waste transported either directly to the facility or to a transfer station. Transfer station and haulage costs from the transfer station to landfill would be covered in the disposal part of the tariff.
- The decision for construction of transfer stations in any case should be based on option analysis and detailed cost estimates.
- In some cases, change and optimization of existing waste collection system for direct transportation of waste could be more cost-effective solution than construction of a transfer station.
- The use of small size satellite collection vehicles uploading to a large volume collection vehicle and then direct transportation could be an alternative to a stationary transfer station in case of relatively small waste quantities.
- The cost efficiency of establishing a transfer station depends on transportation distances and waste quantities collected, which in turn depend on the number of residents served.
- The costs for municipal waste transfer should typically be lower than municipal waste collection costs and usually in the range of $8–$20/tonne of waste transferred.
- Transfer stations are usually not considered for transportation distances below 40 km and less than 50,000 residents served.

3.3 Landfilling of waste

Box 6: Main mistakes when planning municipal waste landfill

- The landfill capacity does not correspond to actual waste quantities accepted on site. In case the site receives much less quantities of waste than initially planned, this will lead to considerably higher costs per tonne than initially estimated due to the fixed investment and operating costs that do not depend on landfill capacity. In an opposite case, if the landfill receives much larger quantities than planned, the capacity will be utilized much faster and the overall lifetime of the facility could be reduced.
- Similar to above, if the capacity of a landfill cell exceeds the typical operating period of 5–7 years, this could mean that unnecessary high investments have been done in the initial stage.
- Sufficient funds are not allocated annually for landfill O&M.
- Landfill closure and aftercare costs are not considered in the calculation of landfill gate fee.
- The landfill operation procedures are not strictly followed leading to issues such as inadequate compaction, increased leachate production, and slope instability. These problems may shorten the landfill's lifespan and elevate the cost per tonne of waste processed beyond initial projections. Additionally, incorrect operational practices could lead to severe consequences such as landfill fires.
- Waste not acceptable for landfilling is deposited at site, for example, infectious waste, animal tissue waste, liquid waste. This can pose significant environmental and operational challenges.
- Insufficient or excessive personnel are appointed at the landfill site.
- Mistakes in the landfill design can result in additional costs or operational risks.
- Underplanning or underinvestments in landfill due to unrealistic expectations of transitioning away from landfill to a recovery-based economy within a short period.

Typically, investment costs for the landfill are required for the following:

- Land acquisition
- Establishment of auxiliary infrastructure: access road, electricity supply, water supply, sewer, discharge of infiltrate. It should be noted that external infrastructure costs could be significant and should be considered at an early stage during the site selection process.
- Landfill base preparation: excavations, filling, compaction, leveling, and so on.
- Installation of landfill bottom sealing system: for example, compacted clay, synthetic geomembrane.
- Site infrastructure: fence and gate of the site, internal roads, parking areas, temporary roads during operational phase.
- Buildings: administrative building, workshops, garages.
- Dewatering rainwater: surface water trenches, sewer systems, manholes, and so on.
- Leachate collection and treatment: for example, drainage pipes, aerial drainage, shafts, pumps, measurement equipment, reservoirs, lagoons, wastewater treatment plant for infiltrate/sanitary wastewater, settlement tank, and separating vessel for vehicle washing place.
- Landfill gas collection and management on site: for example, gas collecting pipes, gas drainage, gas wells, gas collecting stations, gas flare, and, if appropriate, equipment for utilization of landfill gas
- Surface capping
- Monitoring wells and equipment
- Machinery, for example, waste compactors, front loaders, bulldozers, trucks, sweeping machine
- Other: transformer and electricity works on site, external lighting, water reservoirs and fire protection equipment, and so on
- Engineering and supervision during construction.

It should be pointed out that landfills are constructed in stages (landfill cells) and the investment costs appear over the whole life of the site and are not limited to the initial investment. The cost estimate should consider the different periods when investments occur:

- Initial investment, usually related to site development, common site infrastructure and construction of first landfill cell(s)
- Investments into second and following cells
- Investment for continues upgrade and expansion of gas collection system
- Costs related to progressive implementation of closure (which normally takes place immediately after commissioning of a new cell), as well as aftercare costs
- Gas collection costs appearing over the whole life of the landfill
- Costs for closure and aftercare related to lifetime of individual cells
- Costs for supply and replacement of equipment.

The following operating costs should be considered when developing costs estimates:

- Personnel costs, including social and health insurances
- Maintenance costs, usually defined as percentage of initial value of asset
- Consumables: fuel, electricity, others
- Leachate treatment and landfill gas management facilities operation and maintenance costs
- Costs for treatment and discharge of infiltrate and wastewater
- Monitoring costs
- Aftercare costs
- Insurance costs
- Administrative costs.

3.3.1 Examples for landfill cost estimates

Landfill costs can typically be disaggregated into the following components:

- Acquisition costs
- Capital expenditure and development costs
- Operating costs
- Restoration
- Aftercare costs.

Unit costs are affected by fill rates and the total capacity/lifespan. The two together effectively determine the period over which waste is accepted and, thereby, the depreciation period for capital. Total capacity determines the projected quantity of waste accepted over the lifetime which can be used as the basis for effectively generating a fund to support aftercare expenditure.

Acquisition costs can vary significantly between sites. In some cases, the site may be acquired outright for a fee, in others, a royalty may be paid or the site may be leased. It is difficult to generalize about the costs of acquisition and much depends on the landowner in determining these costs.

Capital expenditure and development costs are affected by the national legislation in terms of the requirement for landfill base as well as the geology of the site, the site's proximity to sensitive aquifers, and so on.

Operating costs for landfills can be small, while restoration costs are determined more on an area basis than on quantity of material accepted.

The regime regarding aftercare potentially becomes extremely important. This requires adequate financial provisions to be made by the operator to cover the costs of aftercare. Respective national legislation or competent authorities can require (implicitly) funds of differing magnitude to cover these costs. Presumably, those who take a more precautionary approach will require greater provisions (to cover eventualities) than others. This means that the costs of the fund which operators have to generate over the operational life of the site will vary, with consequences for unit costs.

Given these points, differences in unit costs are affected by the following factors:

- Land acquisition
- Technical requirement and level of engineering standards (potentially affected by geology/proximity to sensitive aquifers)

- Scale of the landfill (total void space, average deposition heigh)
- The rate at which the landfill is filled
- Costs for waste compaction and daily cover
- Requirements for gas collection, and where this occurs, the offsetting revenues from sales of energy
- Cost for treatment for leachate
- Financial provisions/aftercare
- Landfill taxes (if applied).

At the initial planning stages, the primary task is determining the required size of the landfill site which is the basis for preparing cost estimates. If no concrete site is considered, the preliminary estimate is prepared based on projections for the quantities to be landfilled, the required lifetime of the landfill, assumed periods of operation and number of individual landfill cells, planned density of deposited waste depending on landfill capacity, and envisaged compaction equipment to be used.[22] The calculation of the required volume of individual cells and landfill is based on the assumption that the final shape of the site will resemble a truncated pyramid. The dimensions of individual cells are calculated for the required waste quantities, based on dimensions at the bottom of the cell, the maximum deposition height, and maximum allowed slope of 1:3. Once space required for the landfill cells is determined, additional space requirements should be determined for administrative buildings, garages, workshops, internal roads, parking areas, weighbridge area, reservoirs, lagoons, wastewater treatment plant, gas management facilities, green areas, and so on. The majority of construction costs associated with the landfill cell are proportional to the space, perimeter length, and length or volume of the specific item.

At later planning and design stages when potential site characteristics are known, volumetric analysis should be updated and the cost estimates need to be adjusted for the actual size, topography, geology, hydrogeology and other site-specific characteristics.

The most uncertain part in the preliminary cost estimates is how to assess the investment requirements and operating costs for leachate treatment on site. The quantity of leachate depends on the quantity and composition of deposited waste, the climate conditions on site and particularly rainfall, the technology of the landfilling, the material cover applied, and daily routines on site. Under these circumstances, the leachate quantities and characteristics could differ significantly between landfills of the same size. The leachate treatment costs also depend on the characteristics of treated wastewater that must be achieved according to local legal requirements and whether the treated wastewater will be discharged into the water body or designated for further treatment in the municipal wastewater treatment system. There are different technologies applied for leachate treatment and different combinations of treatment methods used.[23] If climatic conditions and leachate quantities allow,

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[22] The density of compacted waste depends on waste characteristics, composition and type/weight of equipment used. For small landfill sites where a bulldozer or light (~20 tonnes) compactor is used, waste density of 0.6 to 0.7 tonnes/m3 is achieved. Medium size compactors (~30 tonnes) can achieve waste density of 0.7 to 0.8 tonnes/m^3 and heavy heavy compactors (~40 tonnes) can achieve density of 0.9 to 1.0 tonnes/m^3.

[23] The most common leachate treatment technologies include (a) anaerobic-anoxic-aerobic (A2O) treatment following pretreatment and NH4 removal, (n) membrane bioreactor (MBR); (c) combination of biological treatment with oxygen injection, single-stage ultra filtration followed by activated carbon adsorption; and (d) reverse osmosis (RO) method, following some pretreatment for maximum solids removal. Aerated (evaporation) ponds are also commonly used for leachate treatment sometimes combined with leachate recirculation into landfill body.

part of leachate could be evaporated or recirculated into the landfill body. It should be also considered that leachate quantities change over the lifetime and aftercare period. If there is no clear view about leachate treatment technology to be used, the preliminary cost estimates are provided as percentage of overall investment costs (20–35 percent) by extrapolating the costs of existing landfill site with comparable characteristics or calculated based on unit costs for treatment of 1 m^3 of leachate.

The landfill costs demonstrate significant economies of scale because most of the landfill costs (landfill base, drainage, and landfill cover) are proportional to the area occupied. The large-capacity landfills allow higher average deposition height to be achieved and more waste to be deposited per unit area occupied.

Table 11 shows a comparison of cost estimates prepared for landfills of different sizes corresponding to the five sample municipalities (CAs) considered above in Section 2.3. The costs estimates are prepared for 30 years lifetime of the landfill and 5 years operating time of each landfill cell. The initial investments include the establishment of common site infrastructure (to be used over entire lifetime) such as administrative building and workshops, access road, weighbridge, utilities supply, and the construction of the first landfill cell. The investment costs also include the stationary equipment and mobile vehicles required for normal landfill operation. Investments required for construction of subsequent landfill cells, cells' closure, landfill gas drainage, and treatment occur over the landfill operation period and are not included in the initial investments.

Table 11: Initial investment requirements and annual operating costs for landfills with different capacities

Item	Unit	Landfill example 1	Landfill example 2	Landfill example 3	Landfill example 4	Landfill example 5
Main characteristics						
Population served	Residents	1,000,000	250,000	100,000	50,000	10,000
Landfill capacity	Tonnes/year	400,000	100,000	40,000	20,000	4,000
Lifetime of individual cells	Years	5	5	5	5	5
Maximum deposition height	Meters	25.0	18.0	12.0	8.0	5.0
Average deposition height	Meters	16.4	11.3	8.5	6.5	4.3
Density of deposited waste	Tonnes/m^3	1.0	1.0	0.9	0.9	0.8
Surface of first cell	Thousand m^2	114.3	44.0	8.4	7.3	6.3
Volume of first cell	Thousand m^3	1,880	498	229	116	27
Access road	Meters	500	500	500	500	500
Internal roads	m^2	14,800	9,800	4,700	3,290	1,740
Personnel	Number	51	13	10	5.5	4
Equipment						
Excavator	Pcs.	1	1	1	1	1
Water truck	Pcs.	1	1	1	0	0
Landfill waste compactor (45 tonnes)	Pcs.	1	0	0	0	0
Landfill waste compactor small (30 tonnes)	Pcs.	1	1	0	0	0
Bucket loader	Pcs.	2	1	0	0	0
Bulldozer	Pcs.	2	1	2	1	1
Front loader	Pcs.	0	0	0	0	0
Truck (tip-lorry)	Pcs.	2	1	1	0	0
Street sweeper	Pcs.	0	0	0	0	0

Table 11: Initial investment requirements and annual operating costs for landfills with different capacities (cont.)

Item	Unit	Landfill example 1	Landfill example 2	Landfill example 3	Landfill example 4	Landfill example 5
Pick-up	Pcs.	1	1	0	0	0
Cars	Pcs.	1	1	1	1	1
Investment costs						
Access road, internal roads	$ thousand	460	369	277	252	224
Landfill cell excavation works and sealing system	$ thousand	3,423	1,339	816	545	194
Surface water management	$ thousand	1,084	625	419	344	183
Aerial drainage and leachate collection	$ thousand	3,395	1,472	932	657	274
Leachate treatment plant	$ thousand	2,568	1,284	642	385	-
Fence and gate	$ thousand	152	105	87	76	55
Water supply	$ thousand	64	64	64	64	64
Garage	$ thousand	123	77	46	15	15
Administrative and service buildings	$ thousand	497	215	121	78	20
Other investments on site	$ thousand	723	342	240	214	182
Contingencies (10%)	$ thousand	1,249	589	364	263	121
Mobilization (5%)	$ thousand	687	324	200	144	67
Engineering and supervision (5%)	$ thousand	698	321	197	140	59
Total construction costs	$ thousand	15,123	7,127	4,407	3,178	1,458
Equipment and machinery	$ thousand	3,995	1,995	1,369	669	474
Initial investment costs	$ thousand	19,118	9,120	5,776	3,847	1,933
Operating costs						
Personnel	$ thousand	358	84	65	35	24
Maintenance	$ thousand	804	398	263	141	87
Consumables[24]	$ thousand	1,872	514	289	142	49
Leachate treatment	$ thousand	171	66	41	27	9
Other costs (monitoring, landfill gas management)	$ thousand	189	84	58	45	27
Administration	$ thousand	323	125	75	46	22
Taxes, permits, and insurances	$ thousand	37	13	8	4	2
Annual operating costs (year 1)[25]	$ thousand	3,753	1,283	800	440	220

It should also be considered that a significant part of investment costs occur over the operation period. Table 12 presents an example on how the landfill investment and operating costs develop over the operating period for a landfill cell with an annual capacity of 400,000 tonnes. It should be noted that specific elements of landfill cost estimates are the costs for closure and aftercare. These costs occur after the operation period of the individual landfill but must be considered during the operating phase. In the given example, the costs for closure of landfill cell 1 that physically occur in year 6 are distributed equally over the operating period from year 1 to year 5. Such approach can be considered similar to depreciation in advance and respective provisions for future investments should be made when calculating the annual costs.

The operating costs also increase over the operating period due to increased leachate quantities and closure of individual cells.

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[24] Costs for supply of soil for daily cover not included.

[25] The annual operating costs vary over the landfill operation period due to variations in quantities of deposited waste, quantities of generated leachate, costs for the aftercare of closed cells, and so on. When annual operating costs are shown, they indicate the specific reference year.

Table 12: Landfill investment costs, depreciation and operating costs over lifetime ($ thousand)

	Years												
Item	0	1	2	3	4	5	6	7	8	9	10	11	12
Investment costs													
Ground	–	–	–	–	–	–	–	–	–	–	–	–	–
Buildings and infrastructure	4,113	–	–	–	–	–	193	–	–	–	1,432	–	–
Works Cell 1	8,358	–	–	–	–	–	–	–	–	–	–	–	–
Closure Cell 1[26]	–	–	–	–	–	–	3,378	–	–	–	–	–	–
Works Cell 2	–	–	–	–	–	8,705	–	–	–	–	–	–	–
Closure Cell 2	–	–	–	–	–	–	–	–	–	–	–	3,496	–
Works Cell 3	–	–	–	–	–	–	–	–	–	–	7,479	–	–
Closure Cell 3	–	–	–	–	–	–	–	–	–	–	–	–	–
Mechanical	2,653	–	–	–	–	13	–	–	–	–	39	–	–
Vehicles	3,995	–	–	–	–	–	–	–	–	–	3,995	–	–
Total Investment	**19,119**	**–**	**–**	**–**	**–**	**8,718**	**3,571**	**–**	**–**	**–**	**12,945**	**3,496**	**–**
Depreciation													
Buildings, infrastructure		137	137	137	137	137	144	144	144	144	191	191	191
Civil works Cell 1		1,672	1,672	1,672	1,672	1,672	–	–	–	–	–	–	–
Civil works closure Cell 1		676	676	676	676	676	–	–	–	–	–	–	–
Civil works Cell 2		–	–	–	–	–	1,741	1,741	1,741	1,741	1,741	–	–
Civil works closure Cell 2		–	–	–	–	–	699	699	699	699	699	–	–
Civil works Cell 3		–	–	–	–	–	–	–	–	–	–	1,496	1,496
Civil works closure Cell 3		–	–	–	–	–	–	–	–	–	–	775	775
Mechanical		177	177	177	177	178	178	178	178	178	180	180	180
Vehicles		400	400	400	400	400	400	400	400	400	400	400	400
Total depreciation		3,061	3,061	3,061	3,061	3,062	3,161	3,161	3,161	3,161	3,211	3,042	3,042
Landfill operating costs		3,753	3,773	3,793	3,813	3,992	4,238	4,259	4,280	4,301	4,419	4,642	4,663

The unit costs per tonne of waste deposited for landfills with the sample capacities as presented in Table 11 are shown in Figure 6. These were calculated as AIC over 12-year period at 5 percent discount rate.

As can be seen from Figure 6, the unit costs per tonne of deposited waste increase significantly for landfill sites with small capacity. For that reason, the landfills for smaller population centers are built as regional facilities serving large number of residents across population centers.

In some countries, there exist requirements for the minimum number of residents served by a landfill site or minimum waste quantities received. In principle, construction of landfills serving less than 200,000 residents should be avoided.

Such requirements are correct in principle but should not be applied as a general rule. In specific cases, due to difficult climate conditions or bad road network, the construction of smaller landfills could be economically justified. An optimal balance has to be achieved between the increased waste collection and transportation costs and the reduced disposal costs due to economies of scale associated with larger regional landfill.

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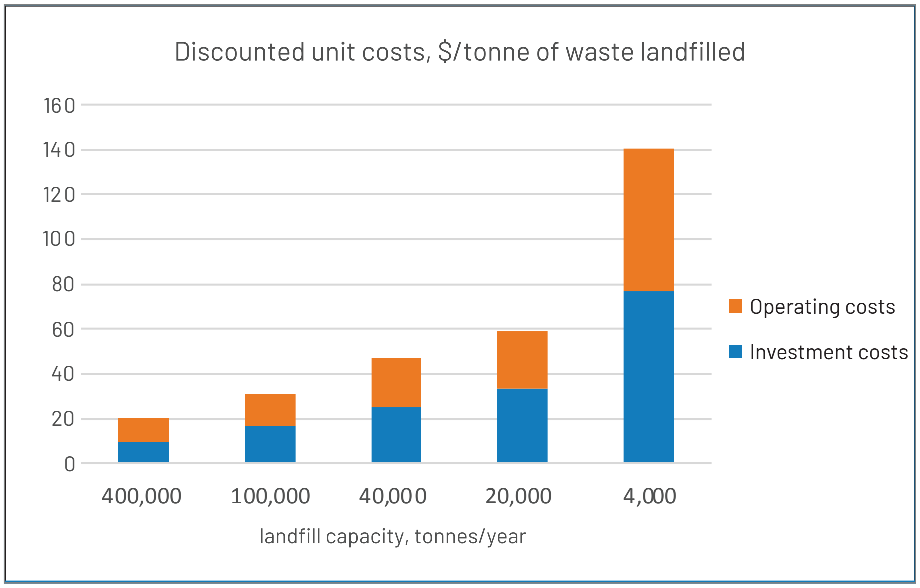
[26] In addition to the cell cover, costs include aerial gas drainage and gas flare.

Figure 6: Unit costs per tonne of waste landfilled at sites with different capacities



Box 7: Tips

- Significant economies of scale exist with the increasing of landfill capacity.
- The typical landfill costs for municipal waste are in the range of $12–$30/tonne of deposited waste, assuming full cost recovery. Higher unit costs are possible if landfill has relatively small capacity that in principle should be avoided.
- The landfill site selection should allow for minimum 20 years operation and preferably possibilities for additional site extension should be available.
- The costs for establishment of additional auxiliary infrastructure such as access roads, electricity supply, and discharge of wastewater could comprise a significant part of overall investment value and should be among the criteria for site selection.
- The landfill design should envisage staged construction with typical lifetime of individual cells of 5–7 years. Landfill cell capacity for longer periods (above 10 years) could also be constructed if investment funding is available.
- Following the initial investment, significant investment costs are incurred over the landfill lifetime for construction of new cells, landfill gas collection, treatment and/or utilization, treatment to increase leachate quantities, closure and aftercare of old landfill cells, equipment replacement, and so on.
- Certain technologies such as gas flares should be made after the initial construction and once the site is operational to establish the appropriate size and type of installation.
- Achieving maximum compaction of deposited waste and minimizing leachate generation are the key factors to keep costs as projected.

3.4 Separate collection of recyclables

Box 8: Main mistakes when planning separate collection system

- Overoptimistic projections of recycling potential of input waste, that is, the amount of recyclable fractions is considerably overestimated.
- Separate waste collection is not supported with appropriate communication and awareness-raising campaign and the number of participating residents is below that was projected and/or quantity and quality of collected materials remains low.
- Overoptimistic projections for capture/source separation rates and household participation rates. This can be partly compensated by additional public awareness measures.
- The proposed separate collection system cannot deliver the assumed/planned separate collection rates.
- Impact of informal sector collection not considered. In case of significant presence of informal waste pickers, the majority of valuable waste fractions will be removed prior to entering the collection system or from within the installed collection infrastructure. In such cases, the quantity and value of the separately collected fractions could be significantly reduced.
- Higher contamination of the separately collected fractions than initially planned.
- Different densities of separately collected fractions not considered when planning the number of necessary containers, collection vehicles, and collection frequencies.
- No precise information about recyclable waste generated from different sources, for example, how quantities are split between the households and commercial/industrial sector not allowing proper planning of the separate collection system.
- Overestimated potential revenues from the sales of recyclable waste commodities resulting from separately collected waste. As a result, the separate waste collection system is not sufficiently financed due to the difference between planned and actual costs and revenues.
- Underestimated logistic challenges of multiplying waste/recyclable streams to manage.
- Organizational challenges for local authorities to shift from closed waste management system to running a recycling business that requires market assessment, commercial arrangements for sales of separated materials, and so on.

Benefits of recycling are now a well-established fact. In terms of both economic and environmental benefits, recycling

- Saves energy and reduces greenhouse gas emissions;
- Conserves valuable resources and reduces the need to extract new raw materials;
- Increases economic security by relying on domestic source of materials;
- Stimulates the development of greener technologies;
- Reduces the need for new landfills and incinerators;
- Creates jobs in the recycling and manufacturing industries; and
- Stimulated research and development (R&D) and innovation.[27]

The separate collection of municipal waste is usually focused on the so-called 'dry' recyclables—paper, cardboard, plastics, metal, and glass—based on the significant quantities of these categories within the municipal waste stream and their recycling potential. Other waste fractions such as textile and WEEE can also be collected for recycling.

The quality of the collected materials is an important aspect for a successful recycling system. Both the demand and the value of recycled materials are directly linked to the way these materials were initially collected.

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[27] GIZ. 2022. *Guideline on Separate Waste Collection and Sorting of Recyclable Municipal Waste.*

There is a direct correlation between separate collection and 'high-quality recycling'. Due to their inherent characteristics, most waste fractions lose quality when collected in a mixed manner and thus become contaminated. High-quality recycling is generally understood to be the reprocessing of waste into materials which have a similar or higher economic value compared to the products or applications from which the waste originates.[28]

Separate collection of recyclable waste should be planned for households and for similar waste with commercial and industrial origin. Commercial and industrial establishments often remove transport and group packaging from the goods sold and recyclable wastes are generated in significant quantities. At the same time, the established on-site separation procedures and practices supported with training of personnel can provide good quality of collected material. The collection schemes and cost structures are in principle different for commercial sector and for households. The reason is that recyclable waste at commercial sites is generated in big quantities that require different methods for storage and/or compaction equipment to be used on site.

When designing separate waste collection, the following should be considered:

- The population density and standard of living, for example, a certain solution can be appropriate in areas with multistorey buildings and an alternative collection system could provide benefits in areas with family houses.
- The type of collection method and whether different methods should be applied in different parts of the area, that is, bring systems such as recycling centers and collection points with containers or curbside systems using individual bins/containers or plastic bags.
- The different collection methods result in different quantities and quality of collected waste fractions. These should be addressed in the collection rates planned to be achieved once the separate collection system is established and when assessing the percentage of contamination in separate collected fractions.
- It should also be considered that household participation in separate collection schemes is crucial for their success. The communication and public awareness measures in combination with incentive schemes could have strong impact on the achieved results.

The key planning elements should generally cover the following:

- The geographical area to be provided with separate collection
- Time frame for implementation
- If applicable, the separate collection and recycling targets to be achieved
- The separately collected fractions
- Type of separate collection system used: container types and volumes, collection vehicles, collection frequency considered. Density of separately collected waste fractions
- The planned capture rates for different materials and also lower and upper limit for collection by weight, in kilograms, per inhabitant and per year
- Expected contamination of the collected fractions
- Distance to the sorting facility.

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[28] Guidance for separate collection of municipal waste, document prepared by EY, PlanMiljØ, ACR+, RWA and Öko-Institut for the European Commission, April 2020.

3.4.1 Examples for separate waste collection cost estimates

Basically, there are two main forms of separate waste collection: door-to-door (curbside) collection and bring system. Both types of collection schemes have been successfully implemented in different cities. The decision whether to implement drop-off or curbside collection schemes depends mainly on the collection rates to be achieved but is also linked with how the residual waste collection is organized, the tariff system in place, people's behavior, presence of informal sector collection, and a number of other factors.

There are few general rules which should be considered when deciding about the type of system to be rolled out:

- The bring systems require more efforts from citizens to reach the containers and discard sorted fractions. In bring systems, the person discarding waste is anonymous and relatively high level of impurities and even residual waste must be expected. In practice that means a lower public participation compared to curbside systems, lower amounts collected, and higher amounts of sorting rejects obtained.
- The curbside collection systems achieve higher collection rates compared to the bring systems but they are more expensive. The quality of the collected materials is higher in case of curbside collection.
- In general, curbside collection needs to be applied in case recycling and recovery targets cannot be achieved via the drop-off system or when there is limited time available to convince residents to participate in the separate collection system.
- Once a curbside system is established using individual bins or plastic bags, it may be difficult to switch to a drop-off system collection and convince people to walk longer distances to discard their waste.
- The same applies for the number of sorted fractions. Once people get used to discarding plastics, paper, and metals together into one bin, it is difficult to convince them to start sorting these materials separately and placing them into separate bins.

Another important decision to be taken is the container types to be used. The size of the container affects quantity, composition (quality), volume, weight, and the unit size of waste collected.[29]

Table 13 provides examples for sizing of different types of separate collection systems for an urban area with 70,000 residents in a municipality with a total population of 100,000 residents.[30] In all considered examples, packaging waste glass is collected separately from other fractions. The reason is that broken glass if mixed with other recyclable materials creates risks for the workers in the sorting plants, additional sorting posts are needed, and could potentially lead to contamination of the other separated materials.

The following alternatives for separate waste collection are presented:

- Alternative 1 (A1): 3 colored 1.1 m^3 plastic euro containers with wheels—one for paper and cardboard (blue), one for plastics and metals (yellow), and one for glass packaging (green).[31]
- Alternative 2 (A2): 3 colored 1.5 m^3 Igloo containers with bottom emptying—one for paper and cardboard, one for plastics and metals, and one for glass packaging

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[29] GIZ. 2022. *Guideline on Separate Waste Collection and Sorting of Recyclable Municipal Waste*

[30] The number of residents is the same as in the case examples for urban areas with collection of mixed/residual municipal waste.

[31] The colors of separate collection containers are indicative.

- Alternative 3 (A3): Comingled mixed recyclables collection in 1.1 m^3 plastic euro container with wheels. Usually referred to dry/wet collection system where all recyclables are collected in one container (dry bin) and all residual waste collected in second container (wet bin). Only costs for collection of dry bin considered.
- Alternative 4 (A4): Comingled collection of paper and cardboard, plastics, and metals in 1.1 m^3 plastic euro containers with wheels; second 1.5 m^3 Igloo container used for collection of glass packaging waste.
- Alternative 5 (A5): Comingled door-to-door collection of paper and cardboard, plastics, and metals in individual 240 liter plastic bins with wheels; bring collection system for glass packaging waste using 1.5 m^3 Igloo containers.
- Alternative 6 (A6): Door-to-door collection of paper and cardboard, plastics, and metals with 120 liter plastic bags; bring collection system for glass packaging waste using 1.5 m^3 Igloo containers.

In all considered alternatives except in Alternative 3, the glass packaging waste is collected separately from other recyclable materials. The reason is that broken glass creates risks for the personnel in the sorting facility and also leads to contamination of plastic and paper fractions which should be avoided.

Table 13: Calculating quantities of separately collected waste and the number of required containers and vehicles for different separate waste collection alternatives

		Alternatives					
Item	**Unit**	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**
Residents provided with separate collection services	Residents	70,000	70,000	70,000	70,000	70,000	70,000
Household waste generated	Tonnes	22,599	22,599	22,599	22,599	22,599	22,599
	kg/capita/year	322.8	322.8	322.8	322.8	322.8	322.8
Separate collection rate per capita[32]	% of generated	13.0	13.0	13.0	13.0	19.4	19.4
Paper	% of generated	50	50	50	50	70	70
Cardboard	% of generated	50	50	50	50	70	70
Plastics	% of generated	30	30	30	30	50	50
Glass	% of generated	50	50	50	50	50	50
Metals	% of generated	30	30	30	30	50	50
Separate collection rate per capita	kg/capita/year	42.0	42.0	42.0	42.0	60.0	60.0
Paper	kg/capita/year	7.3	7.3	7.3	7.3	10.3	10.3
Cardboard	kg/capita/year	13.6	13.6	13.6	13.6	19.1	19.1
Plastics	kg/capita/year	11.6	11.6	11.6	11.6	19.4	19.4
Glass	kg/capita/year	6.5	6.5	6.5	6.5	6.5	6.5
Metals	kg/capita/year	2.9	2.9	2.9	2.9	4.8	4.8
Municipal waste separately collected	Tonnes	3,672	3,379	3,819	3,672	4,624	4,624
Waste separately collected	Tonnes	2,938	2,938	2,938	2,938	4,203	4,203
Paper	Tonnes	514	514	514	514	720	720
Cardboard	Tonnes	955	955	955	955	1,337	1,337
Plastics	Tonnes	814	814	814	814	1,356	1,356
Glass	Tonnes	452	452	452	452	452	452

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[32] 20 percent higher collection rate was assumed for door-to-door collection schemes in Alternative 5 and Alternative 6. Significant variations in the achieved collection rates could be observed depending on residents' participation rates and presence of informal sector.

Table 13: Calculating quantities of separately collected waste and the number of required containers and vehicles for different separate waste collection alternatives (cont.)

		Alternatives					
Item	**Unit**	**A1**	**A2**	**A3**	**A4**	**A5**	**A6**
Metals	Tonnes	203	203	203	203	339	339
Residues (other waste)	Tonnes	734	441	881	734	420	420
Residues	%	25	15	30	25	10	10
Waste density in containers/bags							
Plastic bag	kg/m^3						127
Dry bin[33]	kg/m^3			151	131	109	n.a.
Blue bin[34]	kg/m^3	148	140				
Yellow bin[35]	kg/m^3	91	78				
Green bin[36]	kg/m^3	288	292		288	295	295
Density of containers' sets placed							
Dry bin	Residents/container			195	293	7	
Blue bin	Residents/container	354	449				
Yellow bin	Residents/container	354	449				
Green bin	Residents/container	354	449		464	464	464
Total number of containers installed							
Dry bin	Pcs.			359	239	10,606	
Blue bin	Pcs.	198	156				
Yellow bin	Pcs.	198	156				
Green bin	Pcs.	198	156		151	151	151
Number of 120 liter plastic bags required	Pcs.						394,376
Containers' volume							
Dry bin	m^3			1.1	1.1	0.24	
Blue bin	m^3	1.1	1.5				
Yellow bin	m^3	1.1	1.5				
Green bin	m^3	1.1	1.5		1.5	1.5	1.5
Collection frequency							
Plastic bags	Times/year						26
Dry bin	Times/year			104	104	26	
Blue bin	Times/year	104	104				
Yellow bin	Times/year	104	104				
Green bin	Times/year	18	12		12	12	12
Collection trucks required (including reserve)	Pcs.	1.7	2.6	2.4	2.0	4.1	1.8
Collection trucks running	Pcs.	1.4	2.2	2	1.7	3.5	1.5
New trucks to be purchased	Pcs.	2.0	3.0	3	2.0	4.2	2.2
Total number of containers required	Pcs.	594	468	359	390	10,757	151
Total number of containers to be purchased (including reserve)	Pcs.	634	499	377	410	11,295	159

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[33] Refers to container used for comingled collection of recyclable materials.

[34] Refers to container used for separate collection of paper and cardboard waste.

[35] Refers to container used for separate collection of plastic and metal waste.

[36] Refers to container used for separate collection of glass packaging waste.

The summary of estimated costs for the above separate collection systems is provided in Table 14. The costs for communication and awareness raising are not included.

Table 14: Sample cost estimates for different separate waste collection alternatives

Item	Unit	Alternatives					
		A1	A2	A3	A4	A5	A6
Investments	**$ thousand**	**487**	**1,027**	**394**	**506**	**1,386**	**414**
Containers	$ thousand	231	427	137	227	851	136
Trucks	$ thousand	257	600	257	279	535	279
Operating costs[37]	**$ thousand**	**115**	**140**	**129**	**104**	**203**	**172**
Personnel costs	$ thousand	36	33	49	33	73	37
Fuel costs	$ thousand	30	27	30	23	38	28
Plastic bags	$ thousand						63
Other consumables	$ thousand	4	4	4	3	6	1
Maintenance	$ thousand	20	41	18	20	36	19
Other costs and markup	$ thousand	19	22	21	17	32	18
Insurance	$ thousand	6	14	5	7	18	6
Depreciation	**$ thousand**	**59**	**121**	**45**	**60**	**175**	**47**
Containers	$ thousand	33	61	20	32	122	19
Trucks and vehicles	$ thousand	26	60	26	28	54	28
Costs per container lifted[38]							
Dry bin	$/lifting			4.66	5.17	1.24	
Blue bin	$/lifting	3.7	8.1				
Yellow bin	$/lifting	3.5	5.7				
Green bin	$/lifting	6.7	19.5		19.6	19.6	19.6
Costs per resident served							
Plastic bags	$/resident/year						2.6
Dry bin	$/resident/year			2.5	1.8	4.9	
Blue bin	$/resident/year	1.1	1.9				
Yellow bin	$/resident/year	1.0	1.3				
Green bin	$/resident/year	0.3	0.5		0.5	0.5	0.5
Total annual costs	**$/resident/year**	**2.5**	**3.7**	**2.5**	**2.3**	**5.4**	**3.1**
Average unit operating cost	$/tonne	31.3	41.4	33.7	28.2	44.0	37.3
Average unit depreciation cost	$/tonne	16.0	35.8	11.9	16.4	37.9	10.2
Average unit annual costs[39]	**$/tonne**	**47.2**	**77.2**	**45.5**	**44.6**	**81.9**	**47.5**

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[37] Public awareness costs not included in estimates. Usually more than 10 percent of operating costs until collection system is settled and required participation achieved.

[38] The operating costs, depreciation, and unit costs per container and residents served refer to first year of operation. The costs increase with the increase of quantities of separately collected waste.

[39] The presented costs per tonne are average figures. The costs differ considerably between the collected recyclable waste fractions. Significant deviations are also possible in case of differences in waste composition and capture rates.

The presented average annual unit costs are calculated per tonne of separately collected waste.[40] These unit costs are significantly higher compared to unit collection costs for mixed municipal waste for the same size of settlement (see Table 3 for collection using 1.1 m^3 containers with wheels). The reasons are the lower density of recyclable waste—such as paper, cardboard, and plastics—compared to municipal waste, the smaller quantities collected, and differences in collection frequencies and equipment used.

In the provided example, the separate collection system based on standard 1.1 m^3 containers and requiring separation of waste in only two fractions (dry and wet) has the lowest implementation costs, followed by a similar scheme where an additional container is installed for glass packaging. Nevertheless, it must be pointed out that such a collection scheme is often difficult to implement and good coordination with collection of residual waste is required. Applying dry/wet collection scheme often results in high contamination of dry fraction if households are not convinced to separate waste at source.

Collection schemes using individual plastic bins have the highest implementation costs but result in higher quantities and good quality of collected materials. The separate collection scheme with plastic bags has the lowest investment requirements but high operating costs for the purchasing of plastic bags. It also requires strict collection schedule to be followed to prevent bags with waste from staying on the streets.

Separate collection schemes where residents bring the sorted materials against payment to buy-back recycling centers could also be used.[41] Such buy-back centers usually operate on a commercial basis and mainly focus on high-value materials such as metal scrap, paper and cardboard, polyethylene terephthalate (PET) bottles, clear plastic foils, and some high-value rigid plastics. The buy-back centers may rely on informal waste pickers that deliver waste against payment, while participation of other residents is often low.

Similar to other waste management operations, economies of scale exist when organizing separate collection of recyclable waste. For that reason, recycling programs are usually focused on large urban settlements and then extended to neighboring areas.

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[40] Unit costs for collection of individual recycling fractions (for example, paper and cardboard, and glass) could differ significantly from the average and between materials due to different densities, frequency of collection, and collection equipment used.

[41] Not considered in the present guidelines.

Box 9: Tips

- The success of the separate collection system depends to a large extent on public participation. Appropriate and continuous communication and public awareness measures should be implemented to motivate residents to separate at source.
- The separate collection and sorting of household recyclable waste is a net cost activity, that is, the revenues from the sales of recyclable material are often lower than the combined costs for separate collection and sorting. For that reason, economic instruments and/or EPR schemes may be needed to provide additional financing and guarantee sustainable operations.
- The separate collection costs per capita served in urban areas are expected in the range of $2.5–$5.0 per resident per year. The costs per capita served in rural areas are considerably higher due to the smaller waste quantities generated/collected and higher transportation distances. These costs do not include the public awareness costs that reasonably should be in the range of $0.5–$1.5 per capita at least in the first years of operation or until the separate collection system is fully settled.
- The costs per tonne of recyclable waste collected are different for the different materials/fractions and could vary considerably depending on quantities collected, residents' participation, and the achieved capture rate.
- The separate collection costs must be calculated individually for each separately collected fraction.
- Performance indicators for separate collection should be established at the beginning of implementing the separate collection system. Usually these include container volume provided per capita, quantities collected per capita, and collection costs.
- The role of the informal sector should be considered because it could have a significant impact on the quantity and quality of recyclable waste collected and therefore on the costs and revenues of the entire system.
- Similar to residual municipal waste collection, the number of containers and container sites used should be selected in a way that indicative maximum walking distance from the entrance of a living premise to the container site does not exceed 100 m. In the case of bring system, when possible, the separate collection containers should be installed at the same container sites with containers for mixed/residual waste collection or nearby.
- Separate collection of recyclable waste from households and from commercial, industrial, and administrative establishments requires different technical solutions and cost structures. The collection of *commercial* recyclable waste in large urban areas, if organized properly, should be financially viable at least for cardboard and plastic foils. The reason is that good quality materials are generated in large quantities.
- Implementation of pilot projects to test different collection systems could be appropriate before scaling up to a large number of residents. All data collected during the pilot projects need to be measured and documented.
- Once separate collection is introduced, continuous readjustments could be necessary until desired separate collection efficiency is achieved.

3.4.2 Sorting of separately collected fractions

The separately collected recyclable waste fractions have to be further separated and processed in sorting facilities to meet the requirements of recycling plants.[42]

The sorting facilities are usually established for separately collected paper and cardboard, different kinds of plastic waste, and metal packaging. The simplest sorting facilities comprise of manual picking station and baling presses that could be provided in different configurations and capacities.

Small sites equipped with vertical baling press are usually intended for processing small quantities of 30–60 tonnes of waste per month and are served by few workers, while large sorting plants could process several thousand tonnes per month and have higher personnel requirements.

Small recycling centers usually require less than 1,000 m^2 space small hall or shelter and the only installed equipment is a vertical baler. The waste is fed manually in the

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[42] The facilities designated to separate recyclables are usually called sorting facilities or MRFs. These could be 'clean' MRF for sorting of separately collected waste fractions or 'dirty' MRF for separation of mixed/residual municipal waste.

Box 10: Main mistakes when planning sorting facilities for separately collected waste

- Inappropriate capacity of the sorting facility. The capacity could be too small for the quantity of input waste fractions, for example, due to high quantities of material assumed to be separated by worker at the sorting line or insufficient number of sorting lines. In the opposite case, the installed sorting capacity is overestimated, and the facility could process much higher quantities than actually delivered on site.
- Suboptimal design of sorting facility, that is, the number of sorted fractions is not properly selected and does not correspond to the separate collection system applied; inappropriate equipment used; the sorting facility is not capable of meeting the planned capacity requirements; additional manipulations on site are required and bring additional costs.
- Insufficient appreciation and planning (physical and financial) for the management of rejected materials and their transport to disposal, resulting in residual waste accumulation on site. Design requirements are not initially considered (for example, providing appropriate working conditions through ventilation and exchange of air in sorting cabins, labor safety requirements, and fire protection requirements) that result in additional costs.
- No proper decision on the separated fractions, for example, separation of foils by color can increase the revenues from sales and additional separation operations are required.
- The separated fractions do not meet the quality requirements of the recycling industry.
- Inappropriately selected compaction equipment is being used.
- No market assessment for recyclables collected and no robust long-term offtake arrangements.

baler that limits the processed waste quantities to less than 2–3 tonnes/day. Such facilities usually deal with high-value recyclables such as cardboard, PET bottles, or clean plastic foils. The size of the bale in this case is small and often the bale unit weight is 40–60 kg. Such bales are loaded manually to transportation vehicles and thus cannot weigh more. Vertical balers with higher compaction force exist, but in this case specialized loading equipment should be available on site.

The large sorting facilities are usually specialized in separation of specific recycling commodities where one facility could deal only with wastepaper and cardboard whereas waste plastics and glass are designated to separate installations. The feeding of waste into the sorting cabin is mechanized using different kind of loaders, feeding systems, and conveyor belts. The feeding and compaction of waste is also automated using large volume channel presses. Over the last two decades there has been a tendency for increased use of specialized equipment, optical sorting, and automation of the sorting process, especially for separation of different kinds of rigid plastics.

The separate collection and sorting of glass should be analyzed independently. In many countries there is no glass industry developed and the recycling possibilities are limited. Typically, the separately collected glass fraction requires a special sorting/treatment plant with a significant input capacity of 50,000 tonnes and above separately collected glass packaging to be economically justified. To organize supplies for such plant capacity, the separate collection system should cover at least 1 million residents and more. The initial investment for establishing such type of glass treatment facility typically exceeds $4 million and treatment costs per tonne of input material exceed $30. Due to the relatively low value of glass material, the availability of glass recycling factory within 200–500 km from treatment site could be a limiting factor because of high transportation costs. Solutions for use of waste glass in the production of concrete and construction materials are often considered as alternative to traditional recycling.

The optimal design of a sorting plant depends on the following main factors:

- Type of waste received

- Quantity of waste
- Quality requirements applied toward output fractions
- Financial resources available
- Site characteristics and logistics considerations
- Desired flexibility with regard to quantity and quality of input waste and requirements toward output fractions.

The development of a cost estimate for a sorting facility comprises the following steps:

- Define the type and quantities of input waste fractions.
- Define the number and type of sorted waste fractions, the required sorting efficiency, and the projected quantities for each output fraction.
- Define the required open and closed storage areas for input waste fraction and separated recyclable commodities, for example, for how many days storage should be provided and what are the maximum waste quantities to be stored on site.
- Define the working days per year and number of working shifts.
- Define the number of processing lines required depending on number and composition of input waste fractions and their quantities.
- Define the number of separated fractions and separation technology for each processing line.
- Confirm the markets for materials and quality and packaging requirements of the markets.
- Prepare the indicative list of stationary and mobile equipment according to assumed technical concept.
- Estimate the length of conveyor belts required based on the selected equipment.
- Estimate the space required for installing equipment and conveyor belts considering the indicative equipment dimensions and sufficient maneuvering space for the mobile equipment and equipment access.
- Estimate the space requirements for internal roads, open storages, pavements, and parking areas.
- Estimate the personnel requirements.
- Define the required area for administrative buildings, garages, and maintenance shops.
- Define the requirements for utilities supply (electricity, freshwater, discharge of wastewater).

The main operating costs for a sorting facility comprise the following:

- Personnel costs: salaries, social and health insurance, personnel protective equipment.
- Maintenances costs: usually defined as a percentage of the initial value for the different categories of assets.
- Consumables: electricity and diesel consumption depending on the type, operating hours, and unit consumption of selected equipment and/or per tonne of input waste/output fraction.
- Cost for storage, transportation, and disposal of sorting residues.
- Insurances, administrative costs, and overheads—usually provided as a percentage of the direct operating costs.

Summary data for two sample sorting facilities with different input capacities of separately collected waste are shown in Table 15. The first one has an annual capacity of 10,000 tonnes/year that roughly corresponds to a municipality with 100,000 residents,[43] while the second example is for a large installation with capacity of 150,000 tonnes/year that will be required if all separately collected waste from the five considered municipalities[44] with total population of 1,410,000 residents is separated at one centralized facility.

Table 15: Sample cost estimates for waste sorting plants for separately collected waste

Parameters	Unit	Facility 1	Facility 2
Capacity[45]	Tonnes	10,000	150,000
Working shifts per day	Number	1	2
Working days per week	Number	5	7
Number of processing lines	Number	1	2
Required site area	m^2	2,800	6,400
Operating personnel	Number	32	260
Investment costs			
Ground	$ thousand	-	-
Civil works	$ thousand	783	1,778
Mechanical equipment	$ thousand	455	2,052
Vehicles	$ thousand	132	283
Others	$ thousand	31	99
Total	$ thousand	1,402	4,212
Depreciation	$ thousand	74	239
Unit depreciation cost	$/tonne input waste	7.2	1.6
Operating costs			
Personnel costs (gross values, including social security and health insurance)	$ thousand/year	161	1,250
Maintenance and repair	$ thousand/year	58	193
Consumables	$ thousand/year		
Electricity	$ thousand/year	27	297
Diesel	$ thousand/year	27	293
Miscellaneous	$ thousand/year	2	24
Transport of residues to landfill	$ thousand/year	4	60
Administration	$ thousand/year	16	102
Insurances	$ thousand/year	3	20
Total operating costs	**$ thousand/year**	**298**	**2,239**
Unit operating costs	$/tonne input waste	29.0	14.9
Annual costs[46]	**$ thousand/year**	**372**	**2,478**
Unit annual costs	$/tonne input waste	36.2	16.5

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[43] Assumed 100 percent coverage of urban population of 70,000 residents and 70 percent coverage of rural population of 30,000 residents.

[44] Municipalities with 10,000 residents, 50,000 residents, 100,000 residents, 250,000 residents, and 1,000,000 residents.

[45] No glass treatment envisaged in both facilities for comparison and only storage costs included.

[46] Revenues from the sales of materials not considered.

Box 11: Tips

- Significant economies of scale exist with the increase of sorting capacity. Construction of small size installation processing only few tonnes of recyclable waste per day should be avoided. It should also be noted that better sales prices can be achieved for larger quantities of recyclable materials.
- If properly designed, the revenues from the sales of recyclables should considerably exceed the sorting costs but in most cases will still not be sufficient to cover the combined separate collection and sorting costs.
- Performance indicators for sorting efficiency should be established at the beginning of operations. Typically, these include quantity of separated materials per unit input waste (sorting efficiency), costs per tonne of separated material, revenues per tonne of separated material, and others.
- The market demand, quality requirements, and purchasing prices for different types of recyclable waste commodities define the optimal sorted fractions.
- The market for recyclable waste is dynamic and significant price fluctuations could be observed even within short periods.
- The use of low-cost equipment and facilities is not always the most efficient economic solution.
- Separate collection and sorting systems should be focused on separation of high-quality recyclable materials. Comingled recycling of low-value and contaminated waste should not be considered as sustainable long-term solution.
- Public authorities usually have limited experience and knowledge about the markets of recyclable waste commodities. That often results in nonoptimal operation of the facility, excessive costs, and reduced revenues from the sales of separated materials.
- If separate collection and sorting of household recyclable waste is organized and operated by public authorities, often a parallel system collecting recyclables from commercial and industrial sources is operated by the private sector. The coordination and combination of these two systems in sorting and processing of collected waste could lead to cost optimization as large amounts of waste could be processed in a combined facility.

The costs analysis shows that unit costs per tonne of input waste and per tonne of separated material are considerably lower for the larger sorting facility. The costs for sorting of separately collected fractions are in principle lower than revenues from the sales of separated recyclables. Nevertheless, the revenues from sales of recyclables are not sufficient to cover the combined separate collection and sorting costs for household waste. The costs and potential revenues from recyclables should be considered together as shown in Chapter 7.

3.5 Composting of waste

Box 12: Main mistakes when planning separate collection and composting of green waste

- Alternative separate collection systems and composting concepts and technologies are not sufficiently analyzed at feasibility stage.
- The implemented separate collection system for green/biowaste is not delivering the initially projected quantities.
- Contamination of collected green/biowaste is not considered.
- The composting site is not capable of achieving the initially planned capacity. Seasonal variations in green waste quantities are not considered.
- The composting process takes longer time than initially planned.
- Projected revenues and demand for compost are much lower (or not in place at all) than initially planned.
- The purchased equipment is not appropriate for the quantities of green waste received on site.
- The produced compost does not meet planned quality requirements.
- Insufficient appreciation of the variety and mix of feedstocks and conditions required to create good compost and/or the multidisciplinary regulatory requirements (that is, waste, agriculture, planning, and so on) and marketing needs to ensure that composting is viable.

The biological process of composting involves the breakdown of organic materials by microorganisms. This is a natural biological degradation process where waste is broken down into carbon dioxide, water, nitrates, and sulfates by bacteria that live in an oxygen-rich environment (aerobic). Hence, plant materials such as grass clippings, leaves, and branches are transformed into a useful organic soil improver through a microbiological process.

The composting process comprises of the following two phases:

- **Active composting phase.** Two main processes occur during this phase: intensive decomposition and transformation. The intensive decomposition, referred to also as sanitization, is characterized by high temperature within the piles, whereby the temperature reaches up to 70°C. This stage is mainly promoted by thermophilic microorganisms. This is a process of intense mineralization and loss of water; most of the emissions are linked to this phase. Some form of turning/rotation for aeration of the material should be conducted regularly to prevent temperatures from exceeding 70°C. Aeration also supplies oxygen to keep the microorganisms alive and reduces carbon dioxide, methane formation, and water content of the material. The intensive decomposition is followed by a process of transformation, during which the rate of degradation decreases and metabolites start to be formed. The temperature drops to 30°C–55°C.
- **Maturation/curing phase.** During the maturation phase of the compost, a humus mass is formed. The temperature is lower than 45°C. The process is characterized by reduced transformation and formation of new compounds. During this phase, the lignin compounds are degraded and the material is gradually stabilized.[47]

  The composting activities aim at achieving diversion of organic waste from landfilling and return of valuable organic fraction for reuse.[48]

Types of wastes that are suitable for composting include the following:

- **Green waste.** Waste coming from public spaces such as parks and cemeteries or private gardens (such as grass, tree and shrub pruning, and flowers).
- **Market waste.** Fruit and vegetable residues from markets.
- **Organic waste from agriculture.** Waste from food and animal feed processing or the processing of agricultural products for other purposes.
- **Food waste** includes both cooked and raw materials left over after the preparation and consumption of human food. The source of origin can be either households or establishments such as restaurants, canteens, and bars.
- **Sludge from municipal wastewater treatment plants.** To be accepted for composting, the sludge should comply with the limit values for heavy metals in accordance with existing legal provisions. [49]

Different composting technologies such as the following are used:

- **Static pile -** a compost pile, which is formed and then left completely unturned. It is typically constructed on the ground without any equipment or piping for aeration underneath.[50]
- **Open windrows -** composting is done in so-called windrows, which may have a triangular or trapezoid cross-section, and are agitated or turned on a regular basis.

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[47] GIZ. 2022. *Guideline on Composting of Organic Waste in Albania.*

[48] Ibid.

[49] Ibid.

[50] Ibid.

- **Aerated piles -** in aerated piles, also called aerated static piles (ASPs), aeration is conducted by air blower/suction ventilation system through aeration pipes, or ductwork, placed at the base of the piles.
- **In-vessels -** there are many different types of in-vessel composting (IVC) systems, including fixed, portable, and non-rigid vessels.[51] IVC systems are enclosed systems that may involve the following:

Tunnels	Typically, large-scale rectangular vessels made from concrete or steel. Depending on the technology applied, they can be opened (when continuous process is applied) or closed (for batch systems). When continuous, moving floors may be used to move the material. In such cases, loading conveyors are usually used for feeding the material. In batch systems, the material feeding is often conducted by front-end loaders.
Containers	There are a multitude of containerized systems—fixed, portable, varying capacities, requiring forced aeration, or agitated. Almost all containerized composting systems have integrated control systems that monitor temperature and other control parameters and manage water addition.
Bays/Beds	These are enclosed composting systems where the material is placed in long bays or extended beds (made either from concrete or steel). Mixing is achieved by special turning appliances. During the turning process, material is moved along the length of the bay in a continuous flow. The continuous process allows for fresh material to enter the vessel without getting into contact with the material that has already been treated inside. Aeration is typically supplied from the floor of the vessel with a forced aeration system.
Rotating drum	A composting system using a large rotating drum which, similar to bays/beds system, most often adopts a continuous process whereby material is agitated and aerated as it moves along the drum, allowing for the biological decomposition process to proceed. Mixing, aeration, and agitation is achieved by means of air vents and plates on the sides of the drum.
Silos (vertical towers)	A composting system where the material is fed into the top of the sealed vessel on a continuous basis. Composting process takes place while the material moves down through the silo. There is a flexibility in designing such systems. A system may consist of several vessels each with a single compartment. Alternatively, single larger vessel is used with several compartments. Silos may be perforated to allow aeration during decomposition or to use forced aeration systems. During its retention time, the material moves down the vessel under gravity and is usually removed by augers.[52]

Source: GIZ. 2022. *Guideline on Composting of Organic Waste in Albania.*

Apart from composting installations, home composting (on-site composting) is performed by people in their own garden or house and the resulting compost is used for their own farming and landscaping purposes. In the most ordinary way, the process of home composting requires simply piling up green waste. The decomposition process is aided by shredding plants and branches from trees. To speed the process of decomposition, proper aeration should be ensured by regularly turning the mixture. Kitchen waste could also be added to the process though only selected food waste products are suitable. Dairy products and meat should be avoided as they attract rats and other vermin.

Home composting can be facilitated by use of special devices. These devices (home composters) are stable (usually made of recycled plastic) and have an operational period of 7–10 years. A home composting unit can also be made from wood, or other materials, and can be simple and inexpensive.

For collection of green waste from households, the most common collection methods are public drop-off sites, scheduled curbside collection, or collection with individual bins, sometimes together with other biowaste such as vegetable and fruit residues. If not composted on the site of generation, the green waste is transported

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[51] Ibid.

[52] Ibid.

to a composting facility. To reduce the transport cost, mobile chippers or shredders could be used to increase the density of the transported green waste.[53] Chippers vary widely in their capacity and can be self-propelled or power take-off (PTO) driven.

The key considerations when planning a composting system are

- Whether to give priority to home composting or to implement separate collection of green waste and other biowaste;
- Whether to implement centralized composting installation for all green waste collected from service area or smaller decentralized sites will be more appropriate; and
- What type of composting technology, equipment, and site design requirements will be optimal for the type and quantities in the specific case.

In general, home composting is the appropriate solution for rural areas while composting installations usually serve more densely populated areas.

Centralized large-scale facilities usually accept several thousand tonnes of waste per year while decentralized small sites can treat a few hundred tonnes of waste close to the place of generation. If the decentralized model is applied, usually mobile equipment is used for shredding, turning, or sieving, which can also be shared between more than one facility.

The choice of the system depends on land availability, the quantities of green waste generated, and their distribution within the planning area, how the maintenance of public green areas is organized, the applied collection scheme for the green waste and related costs, already available equipment, technical requirements applied toward composting sites, and so on. In many countries no special requirements exist for composting sites accepting less than 200–300 tonnes/year and composting can be done directly on agricultural land. Such decentralized models reduce considerably the investment costs for construction of composting site and no costs are incurred for collection and treatment of leachate.

The selection of composting technology depends on the type and quantities of input waste, the legal requirements in place, climate conditions, site characteristics, and other conditions.

While open windrow composting and aerated piles are well-proven technologies for green and market waste, the presence of food waste in the input material requires utilizing closed composting systems to properly manage emissions and odors.

The main capital investments at composting site relate to the following:

- Reception zone and storage of the input material.[54] For large sites, entrance area with weighbridge could be provided
- Area for shredding and mixing the materials could be designated as separate zone or within the storage area
- Areas for intense composting and for maturation of the composted material[55]

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[53] Density up to approximately 0.35 tonnes/m^3.

[54] The carbon-rich slow degrading branches and wood chips from trimming can be stored there for 30-day period. The nitrogen-rich fast degrading trimmed grass should be stored for not more than 24 hours. Grass and leaves should be stored separately from the branches and wood chips. If present, unwanted nonorganic materials should be removed by hand.

[55] For windrow composting, both the active composting and curing phases could take place at the same windrows. The partially composted waste after the IVC process is often composted in the open air (as a secondary composting phase) and involves cooling and stabilization of microbial activities.

- Area for sieving the final product (if not performed directly in the maturation zone)
- Area for storage of the produced compost, covered by metal sheet roof construction
- Hardstand area for mechanical equipment, usually covered by portal framed roof structure
- Reservoir or tank farm for the collected surface water and leachate from the intense composting area (which can be used for irrigating the piles or windrows)
- Office container or small administrative building
- Fire safety equipment
- Other site infrastructure: fence and gate, parking areas, utilities supplies, access road (if relevant)
- Equipment used for shredding, transportation and loading operations on site, windrow turning, and sieving of produced compost
- Other equipment: small fuel station (alternatively mobile diesel refuelling vehicle), compost packing station (if relevant for large quantities)
- Process monitoring and laboratory equipment.

The following factors have serious impacts on costs:

- Legal requirements toward composting site—for large-capacity sites, composting directly on land is not allowed and civil works for site establishment will be required
- Size of the windrows and windrow turning equipment used
- Composting time
- Seasonal changes in green waste quantities—the site should be dimensioned with a significant reserve to process peak quantities
- Composting technology
- The type of composting site pavement: compacted clay, concrete, or asphalt
- Requirements for odor management and the treatment of process air—the air discharged through ventilation systems in case of IVC usually cannot be discharged directly and treatment with biofilter could be required
- Compost leachate treatment requirements—if compost leachate cannot be fully reused within the compost process, windrow covers or composting roofed areas could be needed to minimize the leachate quantity and treatment costs.

Different technologies require different time to produce compost that affects the area required.

Table 16: Sample time required for intensive composting and maturation phases for different composting technologies

Parameter	Windrows	Aerated piles	IVC in containers	IVC in tunnels
Active composting phase	4 to 6 weeks	4 to 6 weeks	3 to 4 weeks	About 3 weeks
Turning required	Once a week	3 times in total	Depends on the system	No turning
Maturation phase	6 to 8 weeks	2 to 4 weeks	About 4 weeks	4 to 6 weeks

Source: GIZ. 2022. Guideline on Composting of Organic Waste in Albania.

In addition to site infrastructure costs, other significant expenditures are related to stationary and mobile equipment used. The main equipment for open windrow composting includes shredders and chippers for input material, compost turning equipment (specialized windrow turners or tractor towing appliances), sieves for compost refining, front loaders, tractors, and other auxiliary equipment. Selection of equipment is highly dependent on the quantities of waste to be composted and the size of the available area.

Open windrow composting requires large areas due to the relatively long process of decomposition of the organic material. Depending on equipment used, composting plants of same capacity could have different sizes based on different dimensions of the windrows. The width at the bottom of windrow typically varies between 2.5 m and 6 m. The height at the top of the windrow is usually 1.0–1.5 m but could also be considerably bigger in case of a wider base. The length of the windrows is decided according to the dimensions of the composting site and quantities of received waste and is usually within the range of 20–50 m. Windrow lengths shorter than 45 m should be used if composting technology envisages the use of windrow cover.

Using larger windrow turners leads to smaller site requirements due to the increased cross-section dimensions of the windrow and reduced space between windrows but have higher investment and operating costs. Composting of green waste in large windrows could also cause operational difficulties due to possible creation of anaerobic conditions within the windrow.

For ASP systems, both size and shape are often dependent on site-specific requirements and land availability. However, if land availability is a constraint and piles need to be formed with maximum height and width, mechanical winders are available too, which, however, will increase the capital and operation costs.

All IVC systems are characterized by the following similarities in terms of equipment and automation:

- In-built systems for automated control of the process, regarding monitoring and control of temperature and moisture and capture of exhaust air emissions
- Dedicated aeration systems
- Management of odors.

Although the composting process is conducted in enclosed systems, IVC systems still require auxiliary equipment for their operations. Shredder, front-end loader, and sieve will still need to be procured or made available for operating an IVC facility.[56]

Capital costs can be divided into three main categories: site development, processing equipment (both stationary and mobile), and process monitoring equipment. Site development costs are dependent on the selected technology of composting. For example, turning windrows with a tractor-pulled turner require larger sites (due to required space between windrows for the tractor), whereas a purpose-built windrow straddling turner will require significantly less space.

Operating costs include noncapital-related costs, such as labor, fuel, electricity, maintenance of equipment, and administration. Labor costs are the main cost item in open windrow composting (between 45 percent and 50 percent of total operating costs), followed by equipment maintenance and fuel (both between 25 percent and 30 percent of total operating costs). In forced aeration composting, electricity used for aeration purposes is usually 10–15 percent of the operating costs (however, this operational cost is mainly offset by the reduced requirement for turning at the active composting stage and therefore reduced equipment maintenance and fuel cost

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[56] GIZ. 2022. *Guideline on Composting of Organic Waste in Albania.*

compared to non-aerated windrow composting). In enclosed composting systems, such as IVC and containers, electricity is [57]the main cost item—about 30 percent of the overall operating costs—which typically exceeds labor costs.

Sample cost estimates for green waste open windrow composting sites of different capacities are summarized in Table 17. The indicated capacities roughly correspond to minimum quantities of green waste expected to be collected in public areas in municipalities with 1,000,000 residents (Facility 1), 250,000 residents (Facility 2), and 100,000 residents (Facility 3).[58] Additional examples of Facility 1a and Facility 2a are provided where windrows are covered with semipermeable cover to prevent leachate generation and keep moisture in windrows.

Table 17: Sample cost estimates for green waste windrow composting plants with different capacities

Description	Unit	Facility 1	Facility 1a	Facility 2	Facility 2a	Facility 3	Facility 3a
Annual quantity of green waste received	**Tonnes/year**	**13,500**	**13,500**	**3,400**	**3,400**	**1,350**	**1,350**
Average daily quantity of green waste	Tonnes/day	36.9	36.9	9.2	9.2	3.7	3.7
Average daily quantity in peak months	Tonnes/day	73.8	73.8	18.5	18.5	7.4	7.4
Composting time[59]	Weeks	12	12	12	12	12	12
Land required	m^2	7,500	7,500	2,500	2,500	1,150	—
Windrows							
Turning equipment[60]		Windrow turner	Windrow turner	Tractor with PTO and towing appliance	Tractor with PTO and towing appliance	Tractor with PTO and towing appliance[61]	Tractor with PTO and towing appliance
Site pavement type		Asphalt	Asphalt	Asphalt	Asphalt	Asphalt	Land
Windrow cover		None	Membrane	None	Membrane	None	None
Windrow height	Meter	1.9	1.9	1.5	1.5	1.5	1.5
Width at top of windrow	Meter	1.0	1.0	1.0	1.0	1.0	1.0
Width at bottom of windrow	Meter	4.7	4.7	4.0	4.0	3.0	3.0
Width between 2 windrows	Meter	1.0	1.0	1.562	1.5	1.5	-
Traversal surface	m^2	5.42	5.42	4.13	4.13	3.00	3.00

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[57] Ibid.

[58] The indicated quantities of green waste refer only to green waste from the maintenance of public parks, gardens, and other public areas. Such quantities could differ considerably for municipalities/cities of similar size due to climatic conditions, density of construction, level of maintenance, and many other factors. The quantities will be considerably higher if green waste from areas with family houses is separately collected.

[59] Not separated between intensive composting phase (4 weeks) and maturation (8 weeks).

[60] There are potential cost savings from reduced turning and watering needs as well as reduced composting time when using membranes, aeration, and so on, that are not considered in these alternatives.

[61] Bigger distance between windrows required in case of tractor and towing appliance compared to self-propelled turner.

[62] 3.0 m between two windrows.

Table 17: Sample cost estimates for green waste windrow composting plants with different capacities (cont.)

Description	Unit	Facility 1	Facility 1a	Facility 2	Facility 2a	Facility 3	Facility 3a
Length of windrow	Meter	40	40	40	40	40	40
Volume of 1 windrow	m^3	217	217	165	165	120	120
Medium density	kg/m^3	0.5	0.5	0.5	0.5	0.5	0.5
Number of windrows required	Number	22	22	7	7	4	4
Staff		8	8	6	6	363	3
Investment Costs							
Ground	$ thousand	-	-		-	-	-
Civil works	$ thousand	330	330	143	143	85	
Machinery	$ thousand	817	817	355	355	216	32
Vehicles	$ thousand	686	782	294	325	163	154
Engineering, commissioning, contingencies	$ thousand	92	96	40	41	23	
Total investment costs	$ thousand	1,926	2,026	832	865	488	186
Depreciation	$ thousand	174	185	75	79	44	19
Unit depreciation costs	$/tonne	12.9	13.7	22.2	23.2	32.7	13.8
Operating costs							
Maintenance and repair	$ thousand	121	131	52	55	30	24
Staff	$ thousand	55	55	37	37	16	16
Consumables	$ thousand	112	112	32	32	18	25
Administration	$ thousand	46	48	20	20	11	9
Insurances	$ thousand	5	5	2	2	1	1
Total operating cost	$ thousand	340	352	142	146	77	74
Unit operating costs	$/tonne	**25.2**	26.1	**41.9**	43.0	56.8	55.1
Total annual costs	**$ thousand**	**515**	537	**218**	225	**121**	**93**
Unit annual costs	**$/tonne**	**38.1**	39.8	**64.0**	66.2	**89.5**	**68.9**
Revenues compost[64]	$ thousand	20	20	5	5	2	2
Net annual costs after revenues	**$ thousand**	**495**	517	**213**	220	**119**	**91**
Annual unit costs	**$/tonne**	**36.7**	38.3	**62.6**	64.7	**88.1**	**67.5**

In the above examples, compost windrows are operated on open sites. If the site should be partly or fully covered by shelter, additional costs should be envisaged although some cost savings would be made during operations through reduced watering needs from having sufficient cover. On the other hand, composting facilities (particularly small to medium facilities) can often be located on and operated by companies employed in other sectors such as agriculture or aggregate processing.

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[63] The indicated staff numbers could be part-time employed or shared with other municipal operations.

[64] Revenues calculated for unit price of $3/tonne compost. Significantly higher revenues could be achieved in case market exists for good quality compost.

In such cases equipment and staff employed to operate the composting facility are often shared by the existing activities, and thus labor and equipment would be part-time employed in composting with only a percentage of depreciation and staff time accounted for in the composting operation, making the cost/tonne less than that presented here.

As can be seen from Table 17, the unit costs per tonne of input waste are considerably higher for the two smaller composting installations and for selected technology and equipment. Some costs savings could eventually be achieved if cheaper site pavement is used or less productive and low-cost equipment for shredding or windrow turning is available or if mobile equipment can be shared by two or more sites. As alternative to Facility 3, an option showing mobile composting equipment propelled by a tractor PTO is shown (Facility 3a). In this case, compost windrows are situated directly at agricultural land at several decentralized sites. Lack of site infrastructure costs allows for partial cost reduction.

Enclosed composting technologies can be used for composting of green waste and are also appropriate for other biowaste. While enclosed systems are more suitable for food waste, it is also possible to compost food waste in open windrows, especially combined with green waste. However, it is recommended that post-consumer food waste is only composted by this means when collected through a separated source collection service and where the facility has mechanisms to control emissions (that is, biofilter with negative air suction through windrow) and robust procedures to ensure the elimination of pathogens.

For comparison, Table 18 presents summary cost estimates for composting installations using IVC in tunnels and ASP technologies for intensive phase, with open windrows used for compost maturation. The examples are provided for installations with capacities of 13,500 tonnes/year and 45,000 tonnes/year.

Table 18: Sample cost estimates for biowaste closed composting installation in tunnels

Description	Unit	Facility 4	Facility 5	Facility 6	Facility 7
Installation capacity	Tonne/year	13,500	13,500	45,000	45,000
Average daily quantity of biowaste	Tonne/day	36.9	36.9	123.3	123.3
Intense composting phase					
Intense composting technology		Tunnels	Aerated beds	Tunnels	Aerated beds
Intense composting time	Weeks	2.9	3.6	2.9	3.6
Tunnels/beds dimensions (weight × height × length)	Meter	4.0 × 5.6 × 20.0	2.5 × 8.0 × 35.5	4.0 × 5.6 × 20.0	3.0 × 8.0 × 35.5
Volume of 1 tunnel/bed	m^3	448	710	448	852
Number of tunnels/beds required	Number	4	3	13	8
Maturation phase					
Maturation technology		Open windrows	Open windrows	Open windrows	Open windrows
Maturation time	Weeks	7	7	7	7
Windrow dimensions (height × bottom width × length)	Meter	1.9 × 4.7 × 40.0	1.9 × 4.7 × 50.0	2.4 × 6.3 × 50.0	1.9 × 4.7 × 50.0
Windrow traversal surface	m^2	5.42	5.42	9.40	5.42
Volume of 1 windrow	m^3	217	318	470	318
Number of windrows required	Number	14	11	21	35

Table 18: Sample cost estimates for biowaste closed composting installation in tunnels (cont.)

Description	Unit	Facility 4	Facility 5	Facility 6	Facility 7
Land required[65]	m^2	5,950	6,950	13,300	18,300
Number of operating staff	Persons	10	8	17	14
Investment costs					0
Ground	$ thousand	-		-	-
Civil works	$ thousand	675	513	1,676	1,992
Machinery	$ thousand	899	730	2,360	1,711
Vehicles and mobile equipment	$ thousand	556	636	1,030	1,063
Engineering, commissioning, contingencies	$ thousand	262	228	636	571
Total investment costs	$ thousand	2,393	2,106	5,703	5,337
Depreciation	**$ thousand/year**	**164**	**154**	**380**	**344**
Unit depreciation cost	**$/tonne**	**12.2**	**11.4**	**8.4**	**7.6**
Operating costs					
Maintenance and repair	$ thousand/year	180	65	407	135
Staff	$ thousand/year	66	54	112	82
Consumables	$ thousand/year	119	116	381	223
Administration	$ thousand/year	53	24	128	45
Insurances	$ thousand/year	12	5	28	9
Total operating cost	$ thousand/year	430	263	1,057	494
Unit operating costs	**$/tonne**	**31.8**	**19.5**	**23.5**	**11**
Total annual costs	**$ thousand/year**	**594**	**417**	**1,437**	**838**
Unit annual costs	**$/tonne**	**44.0**	**30.9**	**31.9**	**18.6**
Revenues compost[66]	$ thousand/year	20	20	65	65
Net costs after revenues	**$ thousand/year**	**575**	**397**	**1,373**	**773**
Average unit costs	**$/tonne**	**42.7**	**29.5**	**30.5**	**17.2**

The IVC facilities, in principle, have higher costs compared to windrow and ASP composting sites with same capacities. On the other hand, they require smaller installation space and provide better opportunities for odor management, considering that all process air from tunnels is designated to treatment. As mentioned above, the IVC could also be used for composting of food waste that could be problematic in case of open windrow technology.

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[65] These areas represent the minimum area required. Additional area may be required for receiving, shredding, and storing green waste and bagging and storing product. Value added product such a raised bed mix that incorporates clay and other additives also requires additional space not accounted for.

[66] Revenues calculated for unit price of $3/tonne compost. Significantly higher revenues could be achieved in case market exists for good quality compost.

Box 13: Tips

- Composting installations could be implemented in various sizes and capacities and different technologies exist depending on the input biowaste.
- It is not economically viable to transport green waste to large distances and therefore composting is best organized close to the place where waste is generated. Consequently, decentralized solutions should always be analyzed and compared as alternative to a large, centralized composting facility.
- Promotion of home composting could be a good and less costly solution for municipalities in rural areas and semi-urban areas with family houses.
- Windrow composting installations demonstrate significant economies of scale and larger facilities processing several thousand tonnes per year have lower unit costs.
- Composting process requires control of moisture content, and water source should be available on site.
- Composting is a lengthy process and open composting sites require significant size of land.
- The possible technical solutions and equipment used could vary significantly even for composting sites that have same capacity and employ similar technology.
- Compost revenues depend on quality, demand, and available outlets. The revenues from compost sales could be significant if compost quality is guaranteed by recognized certification scheme. On the other hand, there are many examples where markets do not exist and no revenue is generated.
- Although composting is a relatively simple process, it takes a trained technician and appropriate resources to ensure the correct feedstock mix and processes are performed to produce a high-grade marketable product. Composting is often regarded as a simple waste process that is allocated to an existing waste management facility operator rather than having a competent and motivated operator brought in. This should be avoided and the operator model should be aligned to the processing needs.

3.6 Anaerobic digestion (AD)

Box 14: Main issues when planning AD facilities

- Significant contamination of input biowaste that requires additional treatment on site
- The implemented separate collection system for green/biowaste not delivering the initially project quantities
- The conditions and costs for connection to electricity grid (in case of electricity production) not sufficiently well analyzed during site selection and feasibility stage
- Lack of market for digestate/compost produced
- The O&M of complex AD facility requires availability of qualified personnel and specific skills.

AD is a technology for controlled anaerobic treatment of biodegradable waste used to transform the organic matter contained in the waste into biogas and digestate valuable as an organic fertilizer or soil improver. In municipal waste management, the AD is mainly used for recovery of separately collected biowaste. It is also used

by industries to handle wastes high in chemical oxygen demand (COD) and as a treatment process for sewage sludge after aerobic wastewater treatment. The production of biogas from controlled AD is one of the principal advantages of the process: it is a renewable energy source that can be used to produce electricity, heat, and fuel (gaseous or liquefied).[67]

The characteristics of the feedstock have significant impact on the AD process and therefore on the biogas yield and the digestate quality. For instance, high metal concentrations in the feedstock can be toxic to methanogenic bacteria. The volatile sol-

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[67] *Best Available Techniques (BAT) Reference Document for Waste Treatment*, 2018,

ids content will affect the extent to which the process needs to be monitored to avoid the damaging effect of overloading. One of the main limits of AD is its inability to degrade lignin (a major component of wood). This is in contrast with the process of aerobic treatment (composting).[68]

Three digestions technologies are most commonly used:

- **Wet digestion:** Solid biowaste is mixed with process water or with liquid waste to provide a diluted feedstock for feeding into the digester. Liquid biowaste can be used directly. In other cases, wet AD plants feed solid waste directly (solid feeder with conveyor screws) into the digester and the dry matter content is adjusted within the digester.
- **Dry continuous digestion:** The digestion vessel is semicontinuously fed with substrate containing 15–40 percent dry matter. There are vertical and horizontal digesters.
- **Dry batch digestion:** A batch is inoculated with digestate from another reactor and left to digest without further mixing. Leachate is recirculated to improve the contact between locally formed organic acids and methane forming bacteria.[69]

The main types of digesters are as follows:

- Vertical digesters with an agitator (typically used in wet digestion facilities)
- Horizontal digesters with a slow transport agitator using plug-flow technology (used in dry digestion facilities)
- Vertical digesters with no mixing using plug-flow technology (used in dry digestion facilities)
- Box or percolation digesters (used in dry batch digestion facilities).

The mixing systems used in the digesters can be (a) mechanical, by means of agitators; (b) hydraulic, by means of pumps that recirculate the su strate; and (c) pneumatic, by recirculating biogas in the digester.[70]

Figure 7 summarizes the AD process.

It is obvious from the description of technology in Box 15 that significant cost variations are possible depending on capacity, input material, pretreatment processes applied, and selected treatment technology.

The AD plans can be of different capacities starting from several hundred tonnes per year to hundreds of thousands of tonnes per year. In some lower-income countries, AD is applied at small scale where large number of small facilities are used by one or several households to produce small quantities of gas used for cooking.

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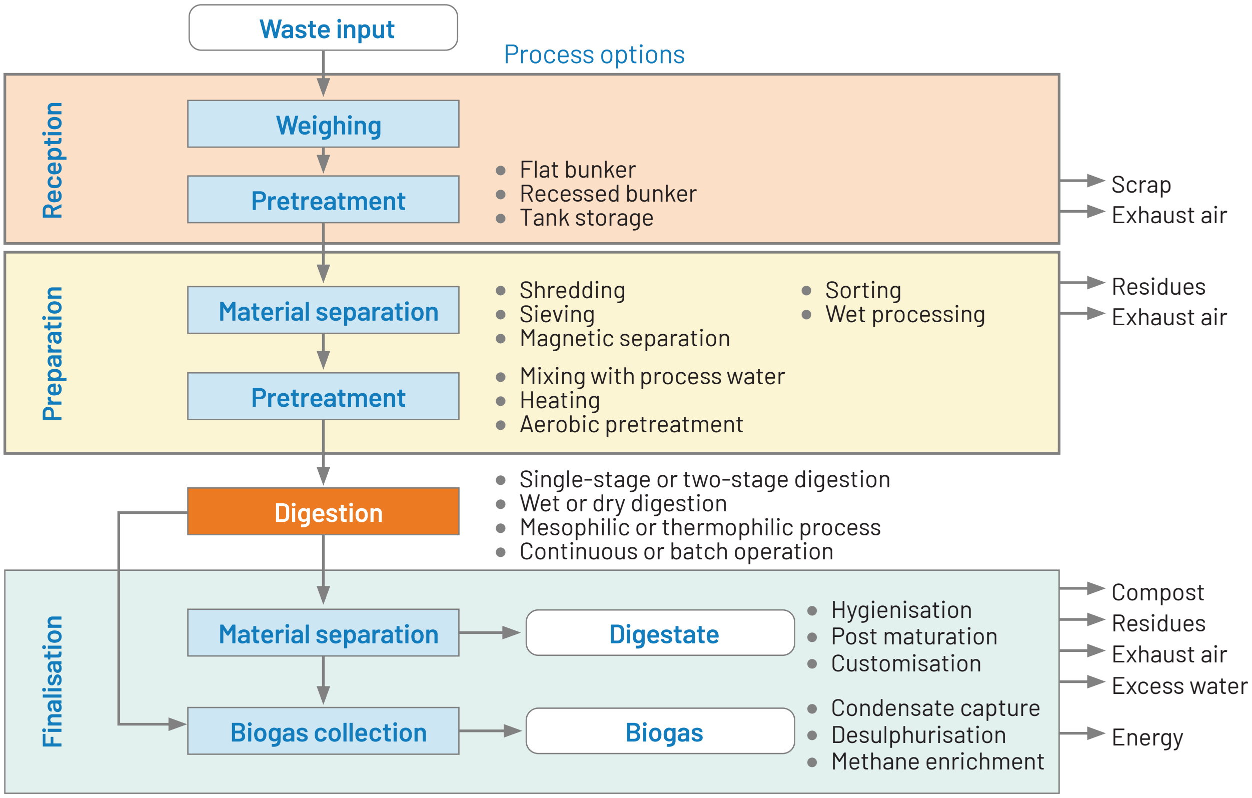
[68] Ibid.
[69] Ibid.
[70] Ibid.

Figure 7: AD process



Source: *Best Available Techniques (BAT) Reference Document for Waste Treatment, 2018.*

Box 15: Use of digestate and biogas produced in AD facilities

The nutrients previously contained in the feedstock remain in the digestate. Only carbon, hydrogen, oxygen (as part of CO_2) and, in marginal quantities, nitrogen and sulfur can leave the process within the gas phase. Therefore, the feedstocks used directly determine the composition of the generated digestate. The nutrient content is predominantly described by the nitrogen, phosphorus, potassium, and organic carbon content. A clean biodegradable feedstock will increase the quality of the digestate, which later can be used as organic fertilizer or soil improver in agriculture, either in a liquid form (about 5–15 percent dry matter) such as manure; or in a semisolid form (10–30 percent) such as peat, or it can be further upgraded for example, by composting, drying; and/or pelletizing in landscaping and horticulture as well as in private gardens. The common practice for digestate produced from AD treatment of separately collected biowaste is post-composting.

Depending on the composition of input biowaste, the energy recovered could result in production of 0.4–0.9 MJ electricity per tonne of waste treated. In addition, combined heat and power (CHP) plants may generate a similar quantity of heat. Total solid residuals depending on waste are 0.3–0.6 tonnes per tonne of input.

Biogas generation can vary significantly, for example, in one plant volumes ranged from 80 Nm^3 to 120 Nm^3 per tonne depending on the waste input. End uses for biogas include burning in a simple boiler to generate heat or use in an engine with a generator to produce power. The most common biogas use is CHP generation to produce both heat and power. Heat is most effectively used on site or locally whereas power can be used on site or transferred to the main electricity grid. Alternatively, biogas can be upgraded, which requires the removal of carbon dioxide and other contaminant gases, to generate biomethane. The addition of propane to biomethane may also be required to achieve the required gas calorific value. Biomethane can be injected into the natural gas distribution network, for conversion to heat or power at the point of offtake or used as a transport fuel. While biogas upgrading may be more efficient in terms of energy utilization, it is also significantly more costly, and biogas upgrading options are not generally viewed as viable for a small-scale AD application.

AD processes may be used to directly treat separately collected biowaste. The inclusion of other feedstocks to separately collected biowaste, such as sewage sludge, alters the resulting digestate. However, it is important to note that the mixing of biowaste with these feedstocks can improve both the environmental and economic aspects of the process and has already been adopted in a number of plants (particularly, co-digestion with slurries and manure at small-scale farm-based plants).

Source: *Best Available Techniques (BAT) Reference Document for Waste Treatment*, p. 353, 354.

Table 19 shows summary cost data for AD plants with capacity of 130,000[71] tonnes of separately collected biowaste per year (Facility 1) and with capacity of 22,000[72] tonnes per year (Facility 2). Costs for separate collection of biowaste are not included.

Table 19: Sample cost estimates for AD facilities with different treatment capacity

Description	Unit	Quantity	
		Facility 1	Facility 2
Annual quantity of biowaste received	**Tonne/year**	**115,000**	**22,000**
Average daily quantity of biowaste	Tonne/day	314	60
Fraction after pretreatment and separation of impurities	%	95%	95%
Land required	**m^2**	**22,000**	**10,500**
Operating staff	Persons	31	24
Investment costs			
Ground	$ thousand	–	–
Civil works	$ thousand	4,182	1,527
Machinery	$ thousand	28,079	8,624
Vehicles and mobile equipment	$ thousand	590	390
Engineering, commissioning, contingencies	$ thousand	9,940	3,143
Total investment costs	$ thousand	42,791	13,685
Depreciation	**$ thousand/year**	**2,733**	**874**
Operation cost	**$ thousand/year**	**3,248**	**1,040**
Maintenance and repair	$ thousand/year	1,786	572
Personnel costs	$ thousand/year	272	140
Consumables	$ thousand/year	437	88
Administration	$ thousand/year	523	167
Insurances	$ thousand/year	230	74
Total annual costs	**$ thousand/year**	**5,981**	**1,915**
Revenues electricity and heat produced[73]	$ thousand/year	3,517	643
Net costs after revenues	**$ thousand/year**	**2,464**	**1,272**
Average net unit costs	**$/tonne**	**21.5**	**57.8**

AD is an expensive technology with high investment and operating costs that considerably exceed the costs for aerobic treatment (composting) for the same installed capacity. The high costs are compensated to a large extent by the revenues from the sales of electricity produced or gas provided to public network, though this is only possible for large capacity installations. The revenues could be considerably higher if preferential tariff applies for electricity produced from renewable sources.

It should also be noted that other solutions for treatment of biowaste could be available at lower costs compared to AD, for example, black soldier fly (BSF) farming technologies for processing food waste, particularly in tropical and subtropical climates where temperature-controlled facilities are not required.

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[71] Corresponds to 50 percent of food waste generated in the five sample municipalities considered with total population of 1,410,000 residents.

[72] Corresponds to 50 percent of food waste generated in a sample municipality with population of 250,000 residents.

[73] Calculated for electricity price of $0.085/kWh without bonuses.

Box 16: Tips

- The construction of AD facility requires well-functioning separate collection system of biowaste to guarantee the feedstock.
- Combined AD facility to receive other feedstock such as animal manure and residues from food processing industry in addition to separately collected biowaste could considerably improve the plant economy.
- Appropriate pretreatment of input biowaste is required to remove plastic bags and other impurities not desirable for the process.
- The conditions and possible technical solutions for the connection to electricity grid should be carefully assessed during the project feasibility stage.

3.7 Sorting and MBT of residual waste

Box 17: Main mistakes when planning treatment of residual municipal waste

- Uncertain quantities and composition of input biowaste
- Uncertain quantities, composition, and granulometry of input residual waste
- Overoptimistic projections of recycling potential of input waste and capture/separation rates achieved, for example, 12 percent of plastic content in input waste does not mean that all of it could be separated for recycling
- Poor understanding of market demand for RDF and quality requirements imposed by final recipients
- Revenue projections for the sales of recyclable materials that are optimistic and, for example, do not consider the lower quality of separated materials from mixed waste compared with separate collection systems.
- Inappropriate sorting concept that results in additional on-site contamination of separated recyclable waste materials, for example, size reduction of input waste with high food waste content is likely to contaminate additionally the paper and plastic fractions
- The separated recyclable fractions do not meet the quality requirements of the recycling industry
- The RDF produced do not meet the quality requirements of recovery installation
- Suboptimal design of the treatment facility that results in additional manipulations on site and/or nonoperational periods and consequently additional costs
- High contamination of the CLO in case of MBT that does not allow its further use (where relevant or allowed by national legislation)
- Future changes in legal requirements not considered at the planning stage (for example, possible ban on use of CLO from MBT in agriculture, new separate collection requirements that reduce the recycling potential of residual waste).

The separation facilities for mixed/residual municipal waste apply mechanical treatment methods such as shredding, sorting, and screening to separate recyclable waste fraction and produce RDF. Such sorting facilities often referred to as MRFs could be 'dirty' MRF for separating mixed/residual waste or 'clean' MRF[74] for sorting separately collected fractions. Some 'dirty' MRFs could also be designed to additionally accept separately collected waste fractions. It should be noted that recyclables recovered from mixed waste are of much lower quality than those from source-segregated waste due to greater levels of mixing and increased potential for contamination with other materials.

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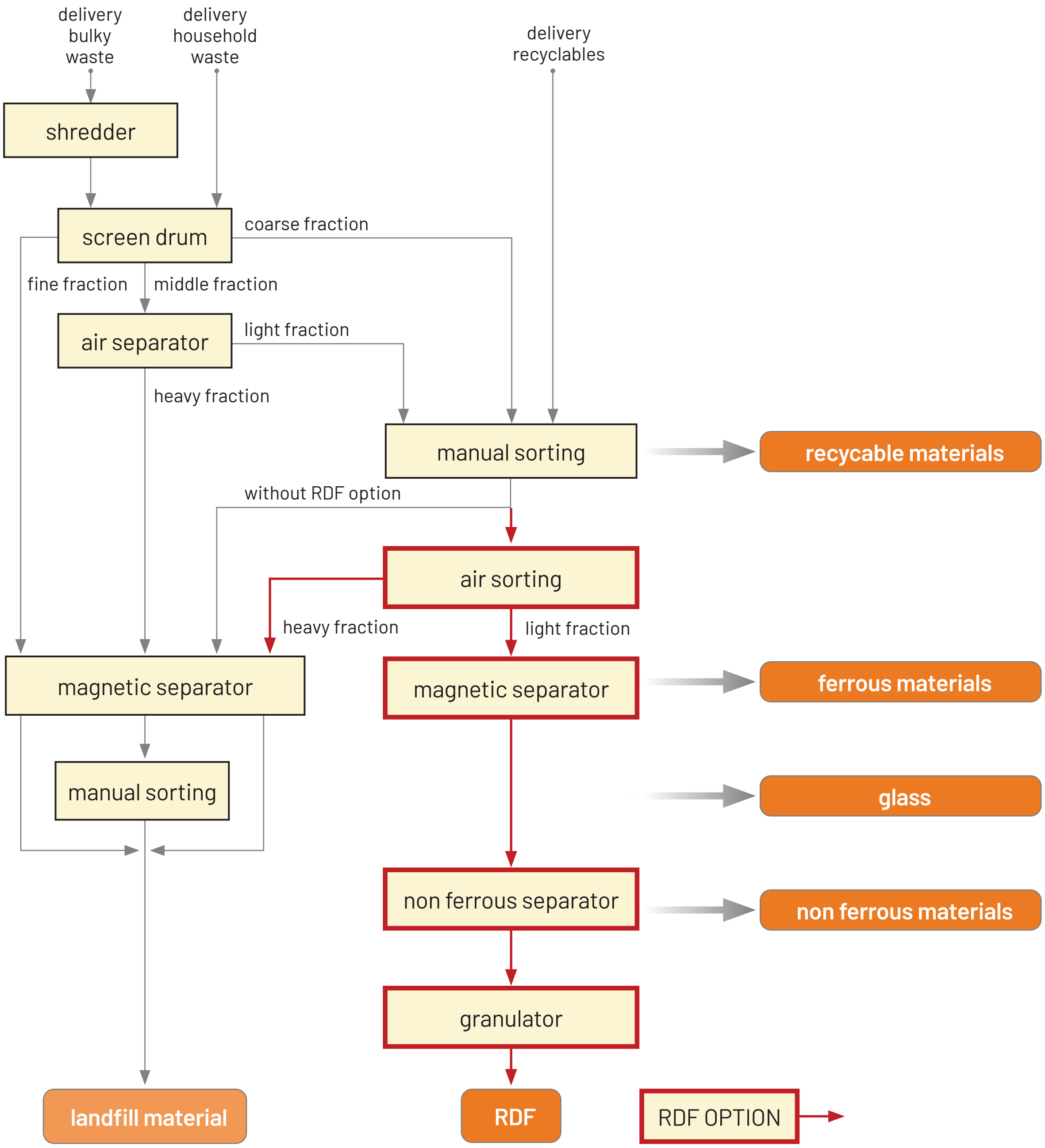
[74] Considered in Section 3.4

Figure 8: Sample diagram for a municipal waste sorting plant



Source: *Feasibility study for construction of sorting plant in Grodno, Belarus*, World Bank. Prepared by Eptisa, RWA Group, u.e.c. Berlin.

The most common waste preparation and sorting techniques are summarized in Table 20.

Table 20: Main waste preparation and sorting techniques

Technique	Separation property/ principle	Materials targeted	Key concerns
Shredder	Rotating knives or hooks rotate at a slow speed with high torque. The shearing action tears or cuts most materials	Mixed waste Bulky waste	May be physically damaged by large, strong objects, exclusion of pressurized containers, shredding too fine early can result in excessive contamination of the CLO fraction.
Bag Splitter	A gentler shredder used to split plastic bags while leaving the majority of the waste intact	Mixed waste	No size reduction, may be damaged by large strong objects
Trommels and Screens	Size	Oversize - paper, plastic Small - organics, glass, fines	Air containment and cleaning
Manual Separation	Visual examination	Plastics, contaminants, oversize	Ethics of role, health and safety issues
Magnetic Separation	Magnetic properties	Ferrous metals	Proven technique
Eddy Current Separation	Electrical conductivity	Nonferrous metals	Proven technique
Air Classification	Weight	Light - plastics, paper Heavy - stones, glass	Air cleaning
Ballistic Separation	Density and elasticity	Light - plastics, paper Heavy - stones, glass	Rates of throughput
Optical Separation	Diffraction	Specific plastic polymers	Rates of throughput

Source: *Mechanical Biological Treatment of Municipal Solid Waste*, Prepared by Enviros Consulting Limited on behalf of DEFRA, 2007.

Some of the considerations that affect the design requirements and costs for the sorting/MBT plant include the following:

- *Plant working days per year and number of working shifts* have a significant impact.
- *Number of processing lines:* A decisive role for design of the processing lines is the quantity of waste that has to be treated per hour. In general, a one-line configuration can handle up to 30 tonnes per hour. If the amount of waste exceeds a certain point, the limiting parts of the process line or, if necessary, the whole line has to be doubled. Limiting parts can be machines (for example, shredder and air separator) as well as a manual sorting line. Besides, higher throughput by adding multiple processing lines has the advantage of not causing the whole plant to shut down if there is any disturbance in a machine. Therefore, the plant's availability grows with the number of lines.
- *Screen fractions:* No matter what kind of sieving machine is used (for example, screen drum and vibration screen) it can be designed with one or more different hole diameters. In general, either a screen with one perforation or with two perfo-

rations is used.[75] The efficiency of a screen with one perforation is higher, that is, less fine fraction material is discharged with the overflow. This means that if the overflow is intended to be RDF material, a better quality is produced. On the other hand, a processing line designed with three fractions means a requirement for two sieves in a row if sieves with only one perforation are used. In that case, the investment costs are higher and more space is required.

- *Sorting technology (manual/automatic):* A main aspect on whether to apply a manual sorting line or an automatic sorting system is the interaction between investment and operational costs. The installation of a manual separation system is limited to a sorting cabin with exhaust air treatment and a capture system for the separated fractions. Automatic sorting systems such as near-infrared technique (NIR) require complex equipment (sensor technology and compressor unit); however, they only work with low material height and limited particle size on the conveyor belts. Manual sorting results in an increased sorting capacity, yet the quality of the gathered materials is reduced.[76] In contrast, the automatic system is able to distinguish between different types of plastic (for example, PET, PE, PS, PVC), paper, wood, and so on. It requires higher initial investments but it is less labor intensive and higher revenues can be achieved.
- *Quality requirements for RDF produced.*[77] The level of preparation that the output fractions need to achieve depends on the purchase agreements with the customers and possible steps of preparation in other preparation plants. This applies to RDF as well as other recycled materials. The requirements toward RDF also affect transportation costs.

MBT implies that besides the processing steps used in sorting plants, additional biological treatment and mechanical processes apply.

MBT is composed of a number of different mechanical and biological process steps which can be modified and combined to meet different objectives. In general, there are four different types of MBT, each of which can be with or without additional sorting plant for recyclables:

- *MBT, producing high-calorific RDF and a biotreated fraction for landfill, with or without production of CLO.*[78] Further in the text, this technology is referred as **MBT1**.

  The biological treatment processes used in MBT1 are similar to composting. Due to potential biological contaminations and odors, the intense biological treatment phase should be enclosed and open treatment is not typically allowed.

  RDF is the current prevalent term used for fuel produced from combustible waste in MBT facilities. Potential outlets for the RDF are cement kilns, purpose-built incinerators with power and heat output (CHP), co-firing with coal at power stations, and industrial-intensive users for power and heat or both based on CHP facilities.

  CLO, also sometimes referred to as ‘stabilized biowaste’, is usually the term used for an output using an aerobic process such as IVC in MBT plant. The potential applications of this output are dependent upon its quality and legislative and market conditions. CLO has the potential to be used as a source of organic matter to improve certain low-quality soil, for example, in the restoration of brown field sites, or for landfill cap restoration, or just landfilled, requiring less volume and generat-

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[75] GIZ. 2025. “Guideline on Separate Waste Collection and Sorting of Recyclable Municipal Waste.”

[76] Ibid.

[77] The quality requirements for RDF are usually defined by final users. Typical parameters to control include particle size, moisture content, and heating value. Limit values for content of chlorine, heavy metals, and other substances should be observed.

[78] The production of CLO requires biological treatment to minimum 8 weeks.

ing fewer methane emissions than landfilling of the original, untreated waste. CLO is not the same as a source-segregated waste derived ‘compost’ or ‘soil improver’ which will contain much less contamination and has a wider range of applications.

- *MBT designated to maximum RDF production and minimum quantity of treatment residues designated to landfill.* Such facilities are usually using bio-drying as treatment method and further in the text is referred as **MBT2**.

  The purpose of this technology is to maximize the RDF production. The mechanical treatment of input waste is organized in a similar way like in MRF and MBT1. The biological treatment is designated to stabilize the material and reduce the moisture content instead of producing CLO.

  Following the biological treatment, the major part of combustible fraction contained in the dried waste is isolated using different separation techniques. The treatment residues containing mainly mineral fraction are designated to landfill.

- *Biological pretreatment before landfilling, sometimes called biological stabilization*. The purpose of such biological treatment is to reduce to some extent the waste quantities designated to landfilling and mainly to reduce the landfill gas generation and contamination of leachate. Such reduction is due to treatment losses from biodegradation processes where the organic matter is partly converted to CO_2 and water. Considering that neither CLO nor RDF is produced, the achieved reduction in quantities of landfilled municipal waste is considerably lower compared to the previous two types of MBT processes (not discussed further in this document).
- *Pretreatment before incineration plant* (not discussed further in this document since WtE facilities are outside the scope of these guidelines).

The last two technologies are not considered below due to limitations in their implementation.

The design of the municipal waste treatment plant should be consistent with the following:

- Type of waste
- Quantity of waste
- Quality requirements of output fractions
- Existing legal requirements and expected future developments
- Financial resources available
- Flexibility to future changes in waste quantities and composition
- Considerations for logistics of output fractions
- Site characteristics.

As a result, the optimal type among the possible design types has to be chosen.

The main capital investments for sorting/MBT plant needed for the following infrastructure include the following:

- Site infrastructure: internal site roads, paved areas, parking areas, site fence, and gate
- Administrative buildings, garage for mobile equipment, maintenance shops
- Entrance area with weighbridge
- Reception zone and storage of the input material.

- Industrial hall for mechanical treatment part sized according to selected treatment concept and equipment
- Storages for final outputs (separated recyclable waste, RDF, and CLO) and, when relevant, loading stations
- Industrial hall and constructions for biological treatment;
- Stationary equipment such as shredders, screens, sieves, compaction equipment and related metal constructions, stairs, and conveyor belts
- Mobile equipment such as loaders, excavators, forklifts
- Site electrical command and distribution
- Process automation
- Ventilation and exhaust air treatment equipment and facilities
- Fire safety system
- Utilities supplies, access road (if relevant)
- Wastewater treatment plant
- Process monitoring and laboratory equipment
- Other equipment: small fuel station (alternatively mobile diesel refuelling vehicle)
- Installation and commissioning.

Sample cost estimates of a residual waste sorting plant and two main MBT technologies are summarized in Table 21. The selected capacity of the installations in the considered examples corresponds to the quantities of residual waste generated in all sample municipalities with total population of 1,410,000 residents.

Table 21: Sample cost estimates for residual waste sorting facility (MRF) and MBT plants

		Facility type		
Parameter	**Unit**	**MRF with RDF production**	**MBT with RDF and CLO (MBT1)**	**MBT with bio-drying and maximum RDF (MBT2)**
Municipal waste input	Tonnes/day	1,240	1,240	1,240
Installation capacity	Tonnes/year	460,000	460,000	460,000
Shifts working		2	2	2
Intense biological treatment type		None	Tunnel	Tunnel
Maturation technology		None	Windrow	
Intense biological treatment time	Weeks	–	4	3
Maturation time	Weeks	–	6	
Waste separated for recycling		26,100	26,100	26,100
RDF high heating value[79] (large size fraction)	Tonnes	47,900	54,900	54,900
RDF low heating value[80] (small size fraction)	Tonnes		–	108,000

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[79] Refers to RDF produced out of large and/or medium size fraction following mechanical separation, containing large percentage of plastics, paper/cardboard, and textile.

[80] Refers to RDF produced from small size fraction following mechanical separation and subsequent biological treatment through biological stabilization or biological/physical drying. It has lower heating value compared to RDF produced out of large size fraction due to the presence of significant quantities of pretreated biowaste, contained in the small size fraction.

Table 21: Sample cost estimates for residual waste sorting facility (MRF) and MBT plants (cont.)

Parameter	Unit	Facility type		
		MRF with RDF production	MBT with RDF and CLO (MBT1)	MBT with bio-drying and maximum RDF (MBT2)
CLO			90,000	–
Pretreated waste to landfill		378,000	114,000	91,000
Site requirements	m^2	13,400	117,000	60,400
Investment costs				
Ground	$ thousand	–	–	–
Civil works	$ thousand	2,860	25,120	20,297
Machinery	$ thousand	7,026	41,617	44,617
Vehicles	$ thousand	685	2,795	1,855
Engineering, commissioning, contingencies	$ thousand	2,957	18,900	18,708
Total Investment costs	**$ thousand**	**13,528**	**88,432**	**85,477**
Depreciation	**$ thousand/year**	**760**	**4,710**	**4,647**
Unit depreciation costs	**$/tonne**	**1.7**	**10.4**	**10.3**
Operating costs				
Maintenance and repair	$ thousand/year	627	3,640	3,626
Staff	$ thousand/year	512	786	746
Consumables	$ thousand/year	1,134	1,644	2,352
Transport of residues to landfill	$ thousand/year	729	220	175
Administration	$ thousand/year	310	1,034	1,089
Insurances and taxes	$ thousand/year	31	103	109
Operating costs	**$ thousand/year**	**3,343**	**7,428**	**8,096**
Unit operating costs	**$/tonne**	**7.4**	**16.4**	**17.9**
Total annual costs	**$ thousand/year**	**4,103**	**12,139**	**12,743**
Unit annual costs	**$/tonne**	**9.1**	**26.8**	**28.2**

The above costs estimates do not consider the revenues from the sales of recyclables and the revenues/costs from the sale of RDF or CLO. It must be noted that although CLO from MBT facilities shares a similar processing as compost, the two outputs should not be confused. CLO is generally not suitable for land application and therefore should not be confused with source-separated green or food waste compost. CLO rarely has a marketable sales value and the value is in stabilizing the material to make it relatively inactive and therefore cheaper to transport and manage in a landfill (producing less gas and leachate, requires less compaction work, and results in less landfill settlement). The potential revenues from RDF produced depend on the achieved quality characteristics and in particular its heating value, moisture content, and particle size. Additional requirements apply for concentrations of heavy metals and other substances. Significant RDF price variations can be observed in different countries and between different users. Revenues can be expected only for high heating value and dry material, while for lower RDF grades the price could be negative.

It should be noted that RDF is not a standard fuel and environmental requirement for waste incineration and co-incineration must apply.

Some recyclables could also be separated from the residual waste entering MBT but their quality is considerably lower than these separated at source. Often there is no market for such contaminated materials and potential revenues are considerably lower.

Sorting/MRF has considerably lower implementation costs but does not provide significant reduction of waste quantities designated for landfilling. The comparison shows comparable costs for the two sample MBT technologies considered. Change in the selected treatment method or output requirements could have a significant impact on costs.

MBT1 and MBT2 examples refer to completely enclosed treatment plants where the ventilation and treatment of exhaust gases is properly organized. The climate conditions in many LICs and MICs allow installation of equipment in open covered areas that could reduce considerably the costs for construction. More simplified treatment concepts could also be considered when limited funds are available. Two additional examples for simplified MBT plants of same capacity are presented to demonstrate possible cost reduction. In these examples, the industrial halls are replaced with shelters and biofilters and other equipment for treatment of exhaust gases are removed; ventilation is limited only to sorting cabins; the MBT tunnels are replaced with open ASPs; and some of the expensive equipment modules (optical sorting and eddy current separators) used to produce RDF are removed. The initial investments for such simplified facilities are estimated to $41.1 million for **MBT1a** and $32.5 million for **MBT2a** while the unit costs are approximately $20/tonne input waste.

Table 22: Sample cost estimates for MBT facilities based on simplified treatment/low-cost concepts

Parameter	Unit	MBT1a (simplified) - MBT with RDF and CLO	MBT2a (simplified) - MBT with RDF
Municipal waste input	Tonnes/day	1,240	1,240
Installation capacity	Tonnes/year	460,000	460,000
Shifts working		2	2
Intense biological treatment type		ASP	ASP
Maturation technology		Windrow	
Intense biological treatment time	Weeks	2.9	2.9
Maturation time	Weeks	7	
Waste separated for recycling		26,100	26,100
RDF high heating value81 (large size fraction)	Tonnes	54,900	54,900
RDF low heating value[82] (small size fraction)	Tonnes	–	108,000
CLO		90,000	–

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[81] Refers to RDF produced out of large and/or medium size fraction following mechanical separation, containing large percentage of plastics, paper/cardboard, and textile.

[82] Refers to RDF produced from small size fraction following mechanical separation and subsequent biological treatment through biological stabilization or biological/physical drying. It has lower heating value compared to RDF produced out of large size fraction due to the presence of significant quantities of pretreated biowaste, contained in the small size fraction.

Table 22: Sample cost estimates for MBT facilities based on simplified treatment/low-cost concepts (cont.)

Parameter	Unit	MBT1a (simplified) - MBT with RDF and CLO	MBT2a (simplified) - MBT with RDF
Pretreated waste to landfill		114,000	91,000
Site requirements	m^2	122,000	58,100
Investment costs			
Ground	$ thousand	–	–
Civil works	$ thousand	4,203	2,924
Machinery	$ thousand	19,936	15,023
Vehicles	$ thousand	8,316	7,886
Engineering, commissioning, contingencies	$ thousand	8,918	7,005
Total investment costs	**$ thousand**	**41,373**	**32,837**
Depreciation	**$ thousand/year**	**2,687**	**2,191**
Unit depreciation costs	**$/tonne**	**5.8**	**4.8**
Operating costs			
Maintenance and repair	$ thousand/year	2,709	2,289
Staff	$ thousand/year	893	852
Consumables	$ thousand/year	1,933	3,044
Transport of residues to landfill	$ thousand/year	219	173
Administration	$ thousand/year	736	691
Insurances and taxes	$ thousand/year	74	69
Operating costs	**$ thousand/year**	**6,564**	**7,118**
Unit operating costs	**$/tonne**	**14.3**	**15.5**
Total annual costs	**$ thousand/year**	**9,251**	**9,309**
Unit annual costs	**$/tonne**	**20.1**	**20.2**

As shown in the above table, the simplified treatment concepts and lower-cost solutions result in reduced treatment costs. However, it should also be noted that cost reduction is achieved as a result of removing some process equipment, applying lower standards for emissions and odor reduction from installation, relaxing labor safety requirements, and so on. As a result, such low-cost solutions have some disadvantages compared to 'standard design' facilities and may not be capable of providing the same operational characteristics, flexibility to changes in input waste quantities, and composition and quality of output products.

The investments costs for establishment of a waste treatment facility can vary significantly depending on the selected technology, desired plant flexibility to changes in input waste composition and quantities, labor safety standard, fire protection measures, and requirements for the output fractions and emissions discarded from installations. The level of automation in the applied technology also has a major impact on investment and operating costs.

Box 18: Tips

- More advanced treatment options usually mean higher implementation costs.
- The materials separated for recycling from mixed municipal waste are of lower quality than the separately collected recyclables and demand and market prices for such materials will be lower.
- RDF producers should meet the requirements of final recovery plants that could vary significantly with regard to size, heavy metal content, heating value, and moisture.
- Revenues from the sales of RDF are not certain and price could be negative if quality requirements are not met.
- Changes in legal requirements could affect the long-term viability of applied technology, for example, if new requirements on CLO are introduced.
- Only proven treatment technologies with significant track record must be considered.

4 Costs of the entire waste management system

Box 19: Main mistakes when planning an overall waste management system

- Not all elements of the system and different waste management operations are taken into account, for example, separate waste collection may be planned without considering how collection of residual waste is organized.
- Investment in waste treatment and disposal infrastructure serving individual settlements in a municipality without looking for regional impact and potential benefits from economies of scale in case of common provision of services at the regional level.
- Overestimated revenues from the construction of treatment facilities for municipal waste and expectations that waste treatment will bring revenues for local authorities.
- Implementation costs for improvement of waste management system and impact on service tariffs not sufficiently analyzed before taking investment decision.

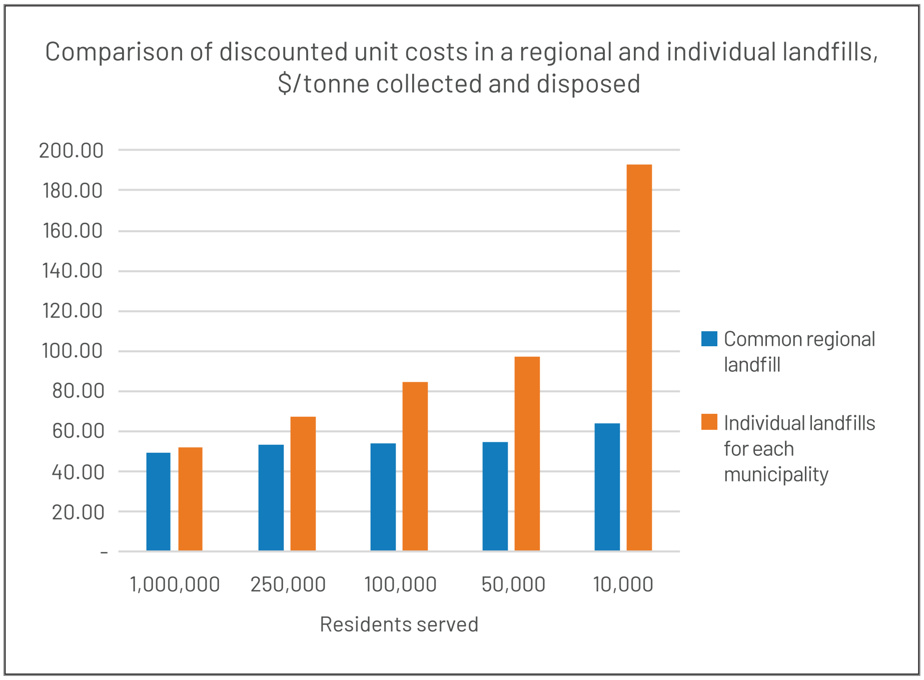
4.1 Individual versus regional provision of services and the effect of economies of scale

Regional waste management planning involves making choices between building several (smaller) waste recovery or disposal facilities usually serving an individual settlement or a municipality or a single (larger) regional treatment site serving several neighboring municipalities.

As noted, if we consider landfill planning, significant economies of scale associated with larger sites can have a major impact on total waste management costs per tonne of waste collected and on the cost per household, as reflected in the tariff. As the affordability of waste management services is a critical element in the decision-making process, optimizing landfill size to maximize potential economies of scale and minimize costs is a key objective of the analysis. Many other factors must also be considered, of which collection, transport, and transfer systems and costs are particularly significant.

To demonstrate this, an example is provided that compares the construction of individual landfills for each of the different-sized sample municipalities considered in Section 2.3, with total population of 1,410,000 residents, with the construction of a single regional landfill serving all municipalities. For simplicity of analysis, it is assumed that all waste collected in the municipalities will be disposed of to landfill. The calculations are prepared for an average distance of 25 km between the municipal centers and disposal site and only waste collection and disposal costs are considered. Unit costs per tonne of waste collected and disposed of are shown in Figure 9.

Figure 9: Unit costs per tonne of waste generated for individual and a shared landfill



In this example, the construction of a regional landfill is clearly more beneficial to all municipalities involved. In practice, the waste management planning deals with much more complicated waste management systems where various collection, separate collection, recovery, and disposal options have to be analyzed as presented in the following section.

4.2 The effect on costs of changing waste management objectives

The purpose of this analysis is to formulate and compare several separate collection and treatment options for a regional municipal waste management system serving all sample municipalities considered in the previous sections with a total population of 1,410,000 residents.

The following alternatives are compared:

- **Alternative 1.** The first alternative provides basic municipal waste collection services where all collected municipal waste is disposed of to a central regional landfill.
- **Alternative 2.** In the second alternative, additional services are introduced and separate collection of recyclable waste such as paper and cardboard, plastics, glass, and metals are provided, covering 100 percent of residents living in urban areas and 70 percent of residents living in rural areas in all municipalities. The separately collected waste quantities are delivered to a centralized regional sorting facility. In addition, composting of green waste collected from public parks and green areas is organized at the municipal level. All residual/mixed municipal waste collected in the municipalities is collected and delivered to a regional landfill. The reduced quantities of waste designated to landfilling compared with the previous alternative are considered when calculating the necessary landfill capacity and costs.

- **Alternative 3**. The third alternative retains the waste collection, separate collection, and composting elements considered in Alternative 2 but all residual mixed waste collected is designated to a centralized sorting facility (MRF) where additional recyclables are separated and RDF is produced. In the MRF, the input waste is separated following size reduction into two waste fractions by size using rotating screens. The large size fraction is then fed into sorting cabins where recyclables are separated manually. The remaining combustible materials from the large size fraction are removed using air separators and following additional size reduction and removal of impurities, RDF is produced. The RDF produced from the large size fraction is further referred to as high heating value RDF. The entire small size fraction is designated to landfilling.
- **Alternative 4**. In the fourth alternative, the MRF is upgraded to MBT with a CLO plant like the one considered in Section 3.7. Two variants of Alternative 4 are considered. In *Alternative 4a*, the entire mechanical part and intensive phase of biological treatment is installed in closed industrial buildings and covered area is provided for windrows. Respective ventilation equipment and cleaning of exhaust from enclosed areas are envisaged. The input waste into the MBT plant is separated in a similar way like in the MRF used in Alternative 3. The small size fraction is designated to biological treatment that is similar to composting. The intensive biological treatment is provided in tunnels followed by a maturation phase in windrows. Following biological treatment, CLO is produced using size reduction, sieving, and separation (requiring significant time of 8–10 weeks). The treatment residues are designated to landfill. The alternative provides additional reduction of quantities of waste landfilled due to treatment losses during biological treatment (mainly CO_2 and H_2O) and CLO produced.

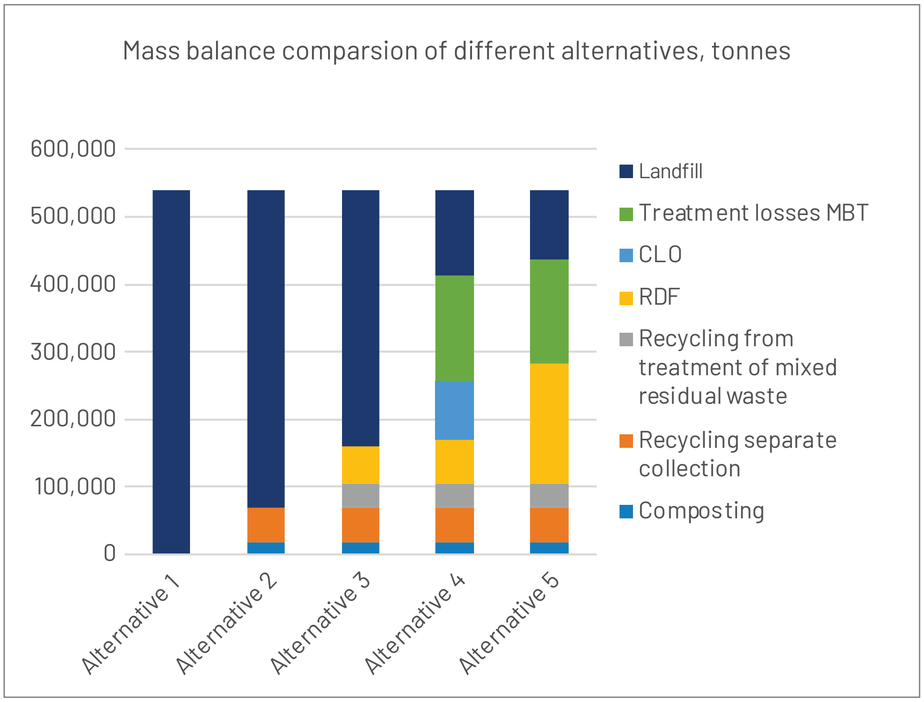
  Alternative 4b has treatment steps similar to *Alternative 4a*. For cost reduction, the mechanical part is installed under shelter and not completely enclosed. Respective ventilation and exhaust air treatment are reduced. The intensive biological treatment is held in ASP beds and some of the RDF processing steps such as removal of nonferrous metals by Eddy current separators, optical sorting, and vibrating screens are not used. The maturation is implemented in an open site.
- **Alternative 5**. In this alternative, the MBT CLO plant is replaced with MBT RDF plant. The change treatment technology's main objective is to maximize the production of RDF and ensure no CLO is produced. The mechanical treatment part of the MBT plant is similar to Alternative 4 and provides separation of recyclables and RDF from the large size fraction. The small size fraction is designated to biological drying in beds/tunnels for 15–20 days. The duration of biological treatment is much shorter than that in Alternative 4. Similar to the previous alternative, two variants are presented with regard to treatment concept as considered in Section 3.7.

  Alternative 5a is for an entirely closed plant, while *Alternative 5b* provides a lower-cost solution where the process equipment is installed under shelter and some of the RDF processing steps such as removal of nonferrous metals by Eddy current separators, optical sorting, and vibrating screens are not used.

Following the approach explained in Chapter 3, detailed mass balances and cost estimates are prepared separately for the different waste operations included for each municipality and for the whole waste management system.

Figure 10 presents the mass balance of all waste generated in the five notional municipalities for the different alternatives during the first year of operation.

Figure 10: Mass balance and comparison of different waste management alternatives



Note: Treatment losses indicate loss of H_2O and CO_2 due to the biological treatment in MBT. Same mass balances assumed for variants of Alternative 4 and Alternative 5.

As shown in the figure, separate collection of recyclable waste and composting of green waste in the second alternative reduce waste to be landfilled by 12.9 percent. Additional reduction of landfill waste to 70.3 percent of municipal waste generated will be achieved if mixed waste is designated to sorting/MRF facility. The construction of MBT under the last two alternatives results in more considerable reduction of landfill waste. The achieved recycling rates and percentage of municipal waste designated to landfill under different alternatives are presented in Table 23.

Table 23: Recycling rate and percentage of waste landfilled for different alternatives

	Alternative				
	1	2	3	4	5
Landfill rate (%)	100	87.1	70.3	23.6	19.1
Recycling rate (%)	0	12.9	19.3	35.1[83]	19.3

Note: In addition to recycling and landfilling, the difference to 100 percent is assigned to RDF produced and treatment losses in MBT process.

The investment requirements increase with the extension of separate collection system and application of more advanced treatment technologies for residual/mixed municipal waste. Comparison of initial investments for the different alternatives considered is show Figure 11.

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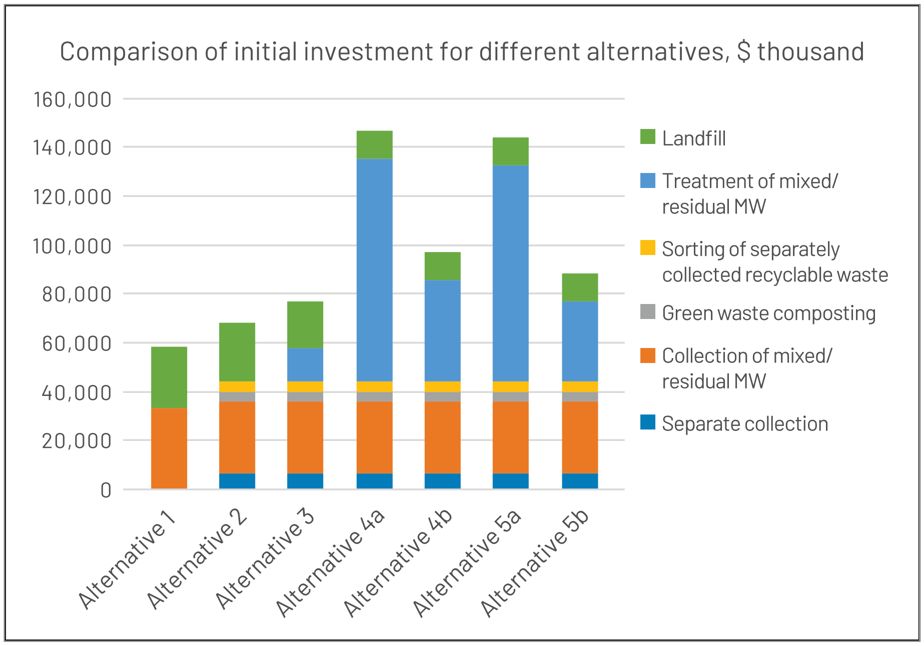
[83] Including CLO.

Figure 11: Estimated initial investment costs for different waste management alternatives



DUCs per waste management operation for the different waste management alternatives are summarized in Table 24.[84] Of note is that the replacement cost of equipment is included in the investment cost.

Note: The presented DUCs (AICs) calculated per tonne of waste generated are **relative** unit costs. They show the contribution that the unit cost of a system component makes to total system unit costs relative to the unit cost contributions of all other components measured against the same base (for example, per tonne of total waste generated). For Alternative 1, these costs are equal to **absolute** unit costs per waste management operation (for example, costs per tonne collected, costs per tonne of waste landfilled). For other alternatives, the absolute unit costs per waste management function are higher than relative values. See explanations in Chapter 5.

The analysis shows that total unit costs per tonne of waste generated considerably increase with the establishment of separate waste collection and composting and increase further with the implementation of more advanced treatment for residual waste such as MRF and MBT. The alternatives with construction of MBT have the highest unit implementation costs. If revenues from the sales of recyclables are considered, the cost increase is partly compensated, and the resulting net costs show smaller differences between alternatives.[85] Such a conclusion should be interpreted with caution because the revenues are not guaranteed and are influenced by many factors as explained in Chapter 7.

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[84] The calculated investment costs consider the initial investments, other investments occurring over the planning period of 12 years, the investment costs for replacement of equipment, and residual value of assets in the end of the planning period.

[85] The conclusion is only valid if assumed separate collection capture rates and quantities of recyclables are achieved and for the assumed prices of recyclable commodities.

Table 24: Comparison of DUCs per tonne of waste generated for different waste management alternatives (AIC)

Waste management operation	Alternative 1	Alternative 2	Alternative 3 (RDF + LF)	Alternative 4a (RDF+CLO)	Alternative 4b	Alternative 5 (RDF)	Alternative 5b
Separate collection							
Investment costs	–	2.31	2.31	2.31	2.31	2.31	2.31
Operating costs	–	5.22	5.22	5.22	5.22	5.22	5.22
Total separate collection costs	–	7.53	7.53	7.53	7.53	7.53	7.53
Residual collection							
Investment costs	9.07	7.86	7.86	7.86	7.86	7.86	7.86
Operating costs	24.11	20.69	20.69	20.69	20.69	20.69	20.69
Total residual collection costs	33.18	28.55	28.55	28.55	28.55	28.55	28.55
Green waste collection and composting							
Investment costs	–	0.88	0.88	0.88	0.88	0.88	0.88
Operating costs	–	1.94	1.94	1.94	1.94	1.94	1.94
Total green waste composting costs	–	2.82	2.82	2.82	2.82	2.82	2.82
Sorting plant's separately collected waste							
Investment costs	–	0.69	0.69	0.69	0.69	0.69	0.69
Operating costs	–	2.38	2.38	2.38	2.38	2.38	2.38
Total sorting plant costs	–	3.07	3.07	3.07	3.07	3.07	3.07
Residual waste treatment							
Investment costs		–	2.31	15.07	7.61	14.82	6.14
Operating costs		–	6.43	14.28	12.13	15.67	13.23
Total treatment plant costs		–	8.74	29.35	19.74	30.50	19.36
Landfill							
Investment costs	8.40	8.04	6.82	3.69	3.69	3.40	3.40
Operating costs	8.99	8.57	7.49	3.06	3.06	2.76	2.76
Total landfill costs	17.39	16.61	14.31	6.75	6.75	6.15	6.15
Totals							
Total investment costs[86]	17.47	19.79	20.88	30.51	23.05	29.97	21.28
Total operating costs	33.10	38.80	44.15	47.57	45.42	48.66	46.21
Total gross costs[87]	50.57	58.59	65.02	78.08	68.46	78.63	67.49

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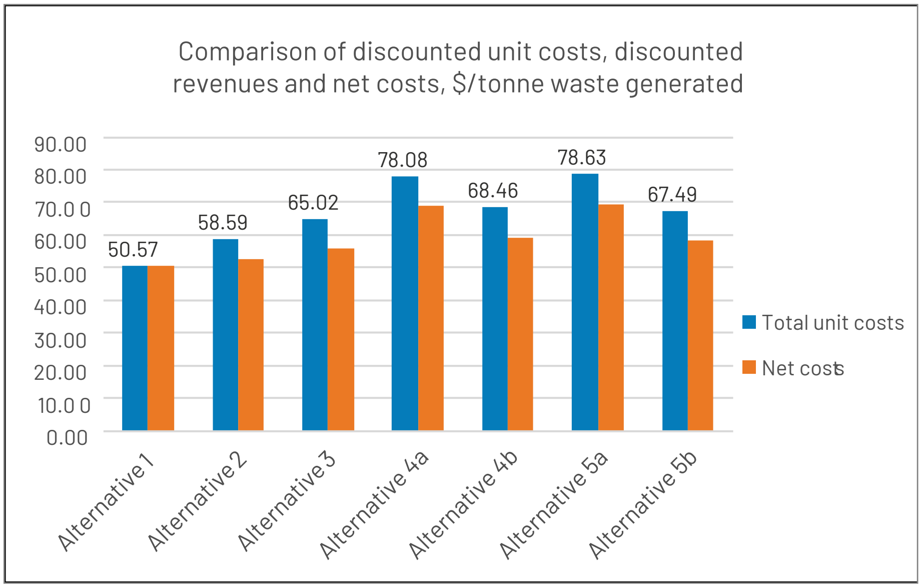
[86] Does not include land acquisition costs for any alternatives, which can have a significant impact.

[87] The potential revenues from the sales of recyclables, compost, RDF, and/or CLO not considered.

Figure 12 summarizes the total unit costs and revenues for the different scenarios. As it can be seen from the analysis, significant cost differences exist between the different waste management alternatives and achieving higher recycling and landfill diversion rates is in principle more expensive.

Figure 12: Estimated unit costs per tonne of waste generated for different waste management alternatives



Box 20: Tips

- The waste management operations are interdependent and an understanding of the costs of the entire waste management system is required.
- Low initial investment does not always mean lowest unit costs.
- More advanced treatment options and technical solutions usually mean higher waste management costs.
- Potential benefits of economy of scale in establishing common treatment and disposal facilities serving several neighboring municipalities should be assessed and common benefits identified at the planning stage.
- Achieving the same technical and quality standards means comparable costs. Waste management investment costs do not depend significantly on the personnel costs and wages. It is not correct to assume that investment in advanced treatment technologies could be implemented much cheaper in countries with lower income. Low-cost solutions usually mean compromise with environmental standards/risks, performance standards/product quality, or labor safety.
- The investment decisions should be based on competent technical expertise, supported by detailed and reliable cost estimates, and not on unproven opinions and expectation.
- It must be noted that social and political aspects affect the availability of land for various facilities and the public acceptance of certain technologies over others can be swayed by perceived and not factual risks, which also influences the availability of options. Additionally, it must be acknowledged that systems such as MBT and energy from waste are never stand-alone and always require landfills for residual waste and/or rejects and off-takes for heat, electricity, recyclables, and so on. Landfills, on the other hand, tend to be more independent as the fail-safe last option. These and other nonfinancial considerations require to be factored into financial decision-making.

5

AIC analysis for municipal waste management

As noted earlier, cost calculations are notional for illustrative purposes only, should be interpreted within the assumptions and unit rates used for their calculations, and should not be considered applicable across the board. Local conditions, technical and technology specifications, markets, and even cultural and social norms influence waste management and its costs and should be considered along with local unit rates when costing a specific system.

5.1 Introductory comments

Earlier chapters have focused on the direct costs of municipal waste management components and shown how those costs vary with differences in scale. Chapters 5 to 7 introduce some financial techniques that are readily applicable to many situations: understanding the financial dynamics of the waste system; evaluating technical options and their cost implications for tariffs and revenue; assessing the financial viability of schemes to collect, sort, and sell recyclable materials; and undertaking longer-term planning, budgeting, and tariff analysis. The chapters illustrate how unit cost analysis is a key tool for systematically analyzing and comparing the costs of municipal waste system options and components.

A primary focus is on unit costs and the insights they bring to effective financial management: translating an uneven cash flow into an equivalent even revenue flow; defining a common tariff to encompass the full costs of all waste components combined; and defining a uniform gate fee for material accepted to an MRF plant even if full plant capacity is progressively phased in over time. Other relevant issues covered are the competing objectives of affordability and financial viability; recyclable material sales, risk, avoided costs, and credits; and understanding the difference between fixed and variable costs.

Chapters 5 to 7 take as an example Alternative 2 presented in Chapter 4 and draw on analysis undertaken with the cost model for each municipality/CA defined by population size (CA 1, 1,000,000; CA 2, 250,000; CA 3, 100,000; CA 4, 50,000; CA 5, 10,000) and for five waste management functions (separate collection, residual waste collection, composting green waste, sorting separately collected material, and landfill operations). Waste and material flows are as per earlier chapters: the populations remain fixed over the planning period whereas per capita waste generation rises at 1 percent a year. Net cash flows, AICs per tonne and per capita, and their equivalent annual revenue flows are estimated. Unit costs of separately collected waste and recyclable materials sorted are assessed. Examples from the cash flow analysis are provided throughout the chapters in the form of summary tables and charts to illustrate unit costs and differences arising from scale.

The data used and examples provided in the main text relate primarily to a notional CA consisting of the populations of all five CAs. A summary of data and unit cost outcomes relevant to each of the five catchments has also been prepared and is included in Annex 1. It provides more detail and examples of techniques described in the text and analysis at different levels, for example, to establish the contribution operating costs (and their individual components) made toward total system unit costs.

The time-period of analysis of the type introduced here depends on the nature of the project being considered. If it is a complex regional waste management system, then planning periods of 15–20 years are realistic. If it is a simple municipal waste collection project consisting of landfill disposal and limited recycling, a period of 10 years may be appropriate. With modern computers, the analysis can be extended over much longer time periods, but the reliability of data inputs and assumptions made over such periods can be poor. The current analysis is based on a 12-year planning period.

The analysis is carried out in the constant values of a specific year—typically the year in which the analysis is being undertaken. The current analysis is undertaken in constant 2022 values. Price adjustments are made over time only if the real price of an input has increased (the rising price of energy in recent times is an example[88]). Adjustments are not made for general price inflation. The discount rate used for analysis of this kind is typically defined by the government. A typical rate for a project conducted in constant values is 5 percent, which is the rate used for the current analysis.

A thorough assessment of the physical flows of a project is crucial. Physical flows typically consist of the populations served (for example, number of households or citizens) and waste and material flows. Provision should be factored in as necessary for projected increases in populations and household numbers—the national statistics agency is likely to publish such estimates. Growth in per capita waste generated (perhaps reflecting rising real income levels) and from a growing population should also be recognized (if reliable data are available).

The effects of changes to current waste and material flows must also be recognized. For example, plans to introduce a waste transfer system to divert waste from small municipal landfills to a larger, more distant regional landfill can have profound consequences for the cost dynamics of waste collection services, transport systems, and landfill disposal. Detailed analysis of the waste and material flows is required, ideally reflected in mass balance diagrams. Material flows analysis is key to defining total capacity requirements and the type, scale, number, and costs of plant and equipment needed to operate the system efficiently over the planning period.

Unit cost calculations are based on a cash flow model linked to the cost model on which the earlier chapters are based. The model does not need to be complex but should ideally be constructed and managed by staff having a good grasp of Excel and the project to be analyzed. Physical inputs are the populations served (residents and/or households) and material flows (waste flows, recyclable material flows, and product sales). A clear understanding of the timing of such flows is important. Financial inputs from the cost analysis are investment costs (from which depreciation, residual value, and ROI are calculated as needed) and operating cost components.

5.2 AIC approach to calculating annual revenue requirements and tariffs

The analysis is undertaken using the techniques of DCF analysis,[89] an extension of which is AIC analysis. AIC analysis enables the full costs of service provision to be allocated over the planning period pro rata to the quantity of waste (or recyclable material) managed each year. The aim is to define a revenue flow which has a PV equal to the PV of the net cash flow, that is, a discounted revenue flow which is equal to the discounted cost flow, and hence covers projected costs in full.[90]

AIC analysis is a powerful and versatile tool that can readily assist in the financial assessment of municipal waste systems. It can assist waste practitioners in

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[88] All prices and costs used in the analysis remain constant, without adjustment.

[89] An overview of DCF analysis (including the concept of PV) is given in Annex 2. The concept of AIC analysis is outlined in Annex 3. Summary descriptions are also given in the Glossary.

[90] The concepts are explained in greater detail in the following sections.

- Understanding the financial structure, dynamics, and constraints of the waste system;
- Evaluating system options and the cost consequences of introducing new system components;
- Identifying the net costs or revenue from the sale of separately collected recyclable materials; and
- Undertaking longer-term systems planning, budgeting, and tariff analysis.

(Note that revenues from product sales are not included at this point in the analysis. This is because sales revenues are far more uncertain than estimates of system costs or tariff revenues. They should be included in the analysis but should not be regarded as definite for feasibility study purposes unless a high level of confidence underpins them [such as successful pilot trials or binding material purchase contracts]. Product sales are considered further in Chapter 7.)

AIC techniques can be used without complex modelling to give rapid information on unit costs/tariffs with only limited investment, operating cost, and physical flow data. AIC relates directly to financial and physical flows (for example, tonnes of waste, citizens) over a planning period and draws on the DCF concepts of discounting, PV, and residual value. The approach transforms an irregular cost flow into an equivalent regular revenue flow. The AIC is a unique value which when applied uniformly to a physical flow generates a revenue flow having a PV equal to that of the cost flow. AIC is calculated from system costs and waste quantities by dividing the PV of the cost flow by the PV of the physical flow.

The steps taken to calculate the AIC and equivalent annual revenue requirements are to

- Calculate the net cash flow;
- Calculate the PV of the net cash flow;
- Define the quantity of waste generated[91] annually over the planning period;
- Calculate the PV of the waste flow;
- Calculate the AIC/tonne of waste; and
- Calculate the annual revenue requirement.

Each step is addressed below.

5.2.1 Calculate the net cash flow

The net cash flow is the bottom line of the cost analysis from which AICs, annual revenue requirements, and tariffs are ultimately calculated. Net cash flow (before accounting for product sales) is calculated as

- Annual investment expenditure, plus;
- Annual operating cost, minus; and
- Residual value[92] of the assets created by the investments.

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[91] Note that the term waste generated is used here to mean the totality of waste material collected (residual waste and separately collected waste collected for recycling). The distinction between the terms waste generated and residual waste collected is significant.

[92] Residual value is the value remaining in a physical asset at the close of the planning period: net cash flow is 'net' of any residual value. It is the value of an asset after subtracting depreciation from the investment expenditure. Residual value is recognized as income in the final year of the planning period.

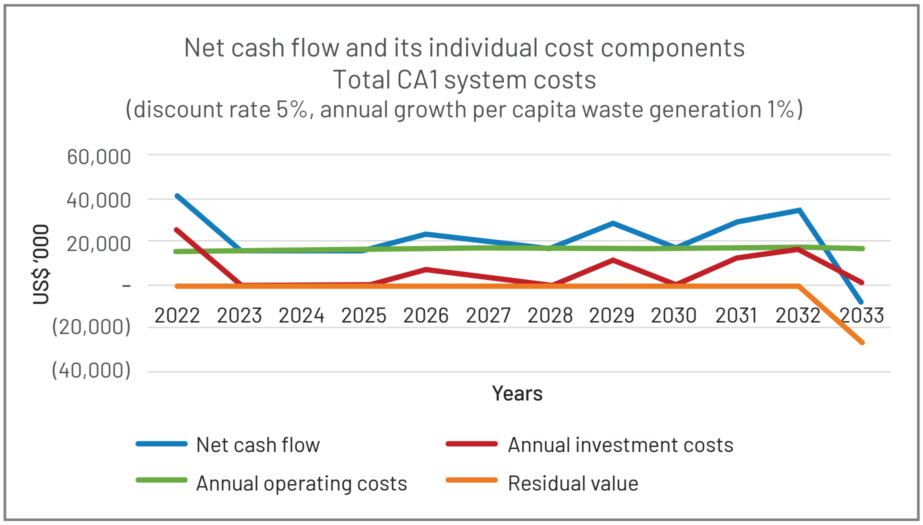
Table 25 illustrates the cost components of the net cash flow: the PV of the waste flow, the PV of the net cash flow, and the AIC per tonne of waste generated as calculated from them. Costs shown in the table relate to the total populations, waste flows, and financial flows of the five waste CAs combined. The PV of the net cash flow is the discounted value of the total costs incurred (investment costs and operating costs[93] net of residual value) over the planning period.

Table 25: Components of the net cash flow (based on the combined CAs)

			Total system
	PV of waste generated	PV of cost component	AIC
Cost component	Million tonnes	$, millions	$/tonne
Net cash flow	4.83	283	58.6
Investments	4.83	117	24.3
Operating costs	4.83	187	38.8
Residual value	4.83	–22	–4.5

Note that the AICs in the table are calculated as the PV of the costs (shown for the total net cash flow and for its individual cost components) divided by the PV of the discounted waste flow.[94] It can also be seen that the PVs of the waste flows on which each AIC is based are the same for each cost component ($4.83 million). This is an important factor, as AICs calculated from the same material base (for example, per tonne of total waste generated[95]) can be totalled together. The AICs for the three cost components sum to the total AIC of the net cash flow. Similarly, the PVs of the three cost components sum to the total PV of the net cash flow. These concepts are expanded below.

It follows that the PV of the net cash flow must also be the PV of the revenue flow needed to cover the costs in full. The net cash flow is typically irregular, combining capital costs of long-lived assets with annual operating costs. The aim is, therefore,



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[93] Accounting-based operating costs, specifically depreciation and ROI, are not accounted for in DCF analysis (as including them would be to double count investment costs and residual value).

[94] Justification for discounting a physical flow (such as waste) is given at the end of Annex 3.

[95] This could also be the PV of total waste collected.

to transform the uneven net cash flow into an equivalent regular annual revenue flow, the PV of which is the same as that of the net cash flow. The two cash flows are equivalent in the sense that their PVs are equal (but whose cash flows are quite different).

Figure 13 illustrates the uneven nature of the net cash flow and its cost flow components (including residual value). The data are from analysis of CA 1.

Figure 13: Net cash flow and cost components

Figure 13 shows the three components of the net cash flow calculation and the net cash flow profile itself. Note that residual value is recognized in the final year of the planning period (from which it can be discounted to define its PV). The uneven profile of the investment expenditure is clear and is reflected in the net cash flow. Annual operating costs grow progressively over the period with rising per capita waste generation, giving a slightly upward trend line. Section 5.2.4 explains how an uneven net cash flow can be translated into an equivalent annual revenue requirement.

The cost flow contributions to the net cash flow are shown at their highest category level (that is, total investment costs, total operating costs, and total residual value.) Note that the unit cost analysis described in this document can be conducted at any subordinate cost level to estimate its unit cost per tonne. Examples include investment categories (civil works, building construction, plant and equipment, and so on.) and operational categories (labor costs, maintenance costs, fuel, energy costs, and so on.) In fact, any activity that can be related usefully to a physical flow.

5.2.2 Define the quantity of waste generated annually over the planning period

The quantity of waste generated is as defined in the cost analysis. The discounted value of the waste flow is calculated in the same way as for a financial flow (see Annex 3 for a justification for discounting physical quantities in this way). The PV of the waste flow is one of the two parameters from which the AIC is calculated, the other is the PV of the net cash flow.

5.2.3 Calculate the AIC per tonne of waste generated

The PV of the net cash flow is also the PV of the revenue needed to fund the waste services on a financially sustainable basis. Calculating the annual revenue requirement depends on first calculating the AIC of the net cash flow. This simply involves dividing the PV of the net cash flow by the PV of the relevant waste flow, giving a fixed unit cost per tonne of waste over the planning period.

Table 26 introduces some key concepts of AIC analysis:

- It broadens the analysis to the combined and individual components of the waste system.
- It shows the PVs of the waste flows for the combined system and its individual components.
- It shows the equivalent PVs for the net cash flows.
- It introduces two types of AIC, one relative and one absolute.

Table 26: Net cash flow by waste component: AIC by waste generated (AIC 1) and actual waste (AIC 2)

Combined total of all catchments	PV of waste flows	PV of net cash flows	AIC 1 (Relative)	AIC 2 (Absolute)
Real discount rate: 5%				
Component	Million tonnes	$, millions	$/tonne	$/tonne
Combined system of all catchments	4.83	283	59	
Separately collected material	0.58	36	8	62
Sorting separately collected material	0.10	15	3	25
Residual mixed waste collection	4.19	138	29	33
Green waste composted	0.16	13	3	82
Landfill	4.19	80	17	19

Key points:

- The AIC of the combined catchments is $59/tonne of total waste generated. It is calculated as the PV of total cash flow ($283 million) divided by the PV of total waste generated (4.83 million tonnes) = $59/tonne of waste generated over the planning period.
- Note that the sum of the AICs (Column AIC 1) calculated for the five functional components is also $59/tonne of total waste generated.
- For example, the AIC for residual mixed waste collection is $29/tonne of total waste generated, calculated as the PV of the cash flow ($138 million) divided by the PV of total waste generated (4.8 million tonnes).
- This outcome illustrates an important characteristic of AIC theory: AICs of waste components calculated from a common physical base (for example, total waste generated) are additive. This enables the relative contribution of each waste component to total costs to be defined.
- AICs calculated in column AIC 2 *relate the costs of each individual waste function to the quantity of material managed by that function*. They are absolute. They cannot be added together, as each relates to a different physical base.
- By providing data on the actual cost per tonne of material managed AICs provide valuable data for waste management planning and a basis for setting gate fees (for example, for landfill) or for setting fees for services provided by local authorities to commercial clients.

Relative and absolute costs per tonne are considered further in Section 5.2.5. Further details on AIC analysis are set out in Annex 3 and in the Glossary.

5.2.4 Calculate the annual revenue requirement

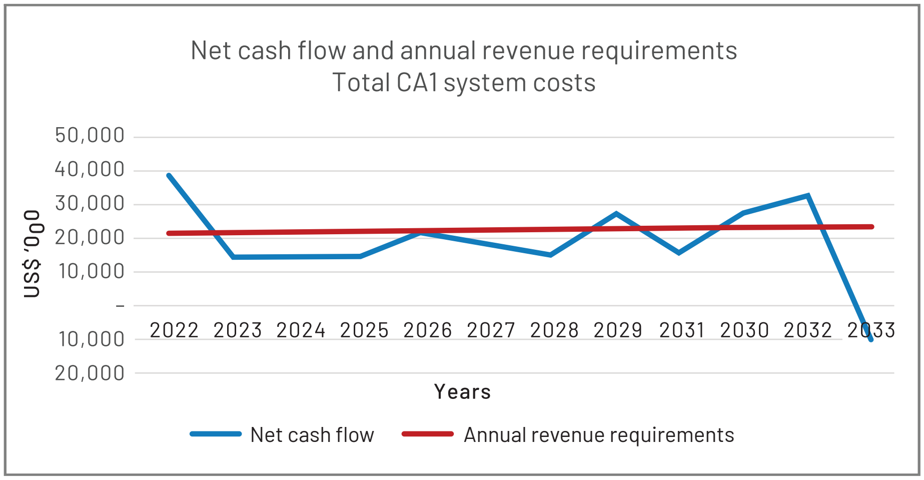
The annual revenue requirement refers to the revenue needed annually over the planning period to cover system costs in full. This does not mean that costs must be recovered in full from user charges but that any gap between the revenue requirement and revenue from user charges must be covered by other sources of funds (such as municipal transfers). It is important to know the total costs in full before deciding on a project and how those costs are to be funded.

The annual revenue requirement for AIC purposes is defined pro rata to the annual waste quantities generated over the planning period. It is calculated by multiplying the relevant waste flow (for example, quantity of waste generated each year) by the

AIC (the unit cost per tonne of total waste generated). It creates an annual revenue flow with a PV equal to that of the annual net cash flow.[96] That is, one which covers the costs in full.

The difference between the net cash flow and the revenue flow lies in the way costs are distributed over time, as illustrated in Figure 14.

Figure 14: Net cash flow and equivalent annual revenue requirement compared



The key point is that the two cash flows have identical PVs. The PV of the smoother annual revenue profile is identical to that of the uneven net cash flow. Note the rising trend in the annual revenue requirement: this recognizes the progressive rise in per capita waste generation and how it is reflected in the annual revenue requirement generated by the AIC.

5.2.5 Absolute and relative AICs

AIC analysis techniques can be used to provide estimates of absolute and relative unit costs:

- By function, such as the direct cost per tonne of material sorted at an MRF plant (a measure of the ***absolute*** or actual unit cost of the function or activity per tonne of material managed)
- By the contribution the unit cost of a system component makes to total system unit costs ***relative*** to the unit cost contributions of all other components measured against the same base (for example, per tonne of total waste generated).

For example, the AIC of separately collected material processed through an MRF plant is defined by dividing the PV of the MRF net cash flow by the PV of the MRF materials flow.

That is, AIC = PV (MRF Net Cash Flow) / PV (MRF Materials Flow).

It is an example of the absolute cost per tonne of operating the MRF plant, measured in $/tonne of separately collected material processed through the plant.

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[96] Note that an AIC can be calculated for any cash flow having a matching material flow (for example, $/tonne of plastic sent to a recycling yard or $/household or person served).

We might also want to know the cost of operating the MRF plant relative to another material flow, such as the total waste generated by the waste system. This is calculated by dividing the PV of the MRF net cash flow by the PV of total waste generated. It is an indicator of the relative contribution made by the MRF plant to total costs.

That is, AIC = PV (MRF Net Cash Flow) / PV (Total Waste Generated).

AICs shown in column AIC 2 of Table 26 relate the total costs of each individual waste function to the quantity of material managed by each function. They are absolute unit costs and *cannot* be totalled together as each relates to a different physical base. For example, the sum of the AIC 2 of $33/tonne of residual waste collected and the AIC 2 of $25/tonne of recyclable waste sorted is therefore meaningless as they are derived from different physical bases. By providing data on the actual cost per tonne of material managed by a specific function AICs contribute valuable information to managers when planning systems, providing a basis for setting gate fees (for example, for landfill disposal or MRF plant) or for setting fees for services provided by local authorities to commercial clients.

AICs calculated on the *same* physical base are additive (as per Table 26, column AIC 1). Here, the AIC for the entire system of $59/*tonne of waste generated* is equal to the sum of the AICs calculated for each of the waste activities from the same base. For example, the AIC of the separate collection service of $8/tonne of waste generated can be added to the AIC of residual waste service of $29/tonne of waste generated to give a combined total of $37/tonne of waste generated. This contributes 63 percent of the total system unit cost of $59/tonne of waste generated (an outcome which may be of interest to the management team).

Unit costs calculated using the AIC approach are a powerful basis for comparing system costs, both in absolute terms (waste component costs allocated pro rata to specific material quantity managed by each component) and in relative terms (waste component costs allocated against a common base), from which the relative contribution made by each function to total system costs can be gauged. Table 27 to 31 summarizes outcomes of the unit cost analysis.

Table 27 illustrates the relative and absolute unit cost outcomes for a notional system consisting of the five CAs combined. That is, the calculations are based on the combined waste flows and the combined investment[97] and operating cost flows. Table 27 shows that the total unit cost (AIC 1) of the notional system is $59/tonne of total municipal waste generated.

Table 27 shows the relative contributions made by each of the waste management functions to the average unit cost per tonne of waste generated:

- Residual waste collection: $29/tonne of total waste generated, 49 percent
- Separate collection of recyclable material: $8/tonne of total waste generated, 14 percent
- Sorted material: $3/tonne of total waste generated, 5 percent[98]
- Composting green waste: $3/tonne of total waste generated, 5 percent
- Landfill: $17/tonne of total waste generated, 29 percent

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[97] Net of residual values.

[98] The unit cost for separate collection of recyclable material of $8/tonne of total waste generated plus for sorting of separately collected material of $3/tonne of total waste generated gives a combined unit cost of separate collection and sorting of $11/tonne of total waste generated (19 percent of total system costs).

- Total system: $59/tonne of total waste generated, 100 percent.

Also shown are unit costs measured in absolute terms, the actual costs per tonne of material managed by each function:

- Residual waste collection: $33/tonne of residual waste collected
- Separate collection of recyclable material: $62/tonne of separately collected material
- Sorted material: $25/tonne of separately collected material[99]
- Separately collected + sorted material: $87/tonne of recyclable waste collected
- Composting green waste: $82/tonne of waste composted
- Landfill: $19/tonne of waste disposed of to a landfill.

Table 27: Unit cost (AIC) per tonne of total waste generated and per tonne managed by function

$/tonne	AICs calculated per tonne of					
Waste function	Total waste generated	Separately collected recyclable material	Separately collected material sorted[100]	Residual waste collected	Green waste composted	Waste disposed of to landfill
	(Relative)	(Absolute)				
Separate collection of recyclable material	8	62				
Sorting of separately collected material	3		25			
Residual mixed waste collection	29			33		
Composting green waste	3				82	
Landfill	17					19
Total municipal waste	59					

Significant differences can exist between absolute and relative AICs for some functions, whereas for others they are small. For example, the difference between the relative AIC for residual mixed waste collection of $29/tonne of total waste generated compares closely to an absolute AIC of $33/tonne of waste collected. This is because the amount of residual waste collected ($4.2 million) is a relatively large proportion (88 percent) of total waste generated ($4.8 million) and hence the difference between the two waste flows over which total costs are allocated is small.

On the other hand, the difference between the absolute AIC for green waste composted of $82/tonne of waste composted is high relative to a small AIC of $3/tonne of total waste generated. The reason for this is that the quantity of waste composted is small relative to total waste generated (3 percent) and hence the *relative* costs of composting are small when allocated across total waste generated. The absolute cost per tonne of material composted is, however, high because the actual costs of composting are inherently expensive.

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[99] The AIC of $87/tonne of separate waste collected and sorted is the combined cost of separate collection of recyclable material ($62/tonne of separate waste collected) and sorting of the separately collected materials ($25/tonne of separate waste collected). The two can be summed as they are both calculated against the same base (separate waste collected).

[100] Note that AICs for separately collected recyclable material and recyclable material sorted are each calculated per tonne of recyclable material collected (the amount sorted being the same as the amount collected). This means that they are additive, giving a total AIC for recyclable collection and sorting of $87/tonne of recyclable material collected.

Table 28 summarizes the *relative* AICs calculated for each activity and catchment. The final column shows the relative AICs for the notional combined CA (as per Tables 26 and 27).

Table 28: Waste function unit costs defined as the AIC per tonne of total municipal waste generated

$/tonne; 5% discount rate	AIC defined by function and CA relative to a common waste flow					
Waste function	CA 1	CA 2	CA 3	CA 4	CA 5	Combined CA
Separate collection of recyclable material	8.0	8.0	8.3	8.6	18.9	7.5
Sorting of separately collected material	3.1	3.1	3.1	3.1	3.1	3.1
Collection of residual waste	27.2	31.1	32.3	32.0	44.6	28.6
Composting of green waste	2.3	3.4	4.5	4.3	14.3	2.8
Landfill	16.6	16.6	16.6	16.6	16.6	16.6
Total municipal waste	56.4	62.2	64.8	64.6	97.5	58.6

The AICs in Table 28 are shown in Table 29 as a share of the total AIC for each CA. This gives insights into the relative contributions made by each waste management function to *total* expenditures.

Table 29: Contribution of each function to total costs by CA (%)

$/tonne; 5% discount rate	CA					
Waste function	CA 1	CA 2	CA 3	CA 4	CA 5	Total combined CA
Separate collection of recyclable material	13	13	13	13	19	13
Sorting of separately collected material	5	5	5	5	3	5
Collection of residual waste	48	50	50	50	46	49
Composting of green waste	4	5	7	7	15	5
Landfill	29	27	26	26	17	28
Total municipal waste	100	100	100	100	100	100

Comparing the PVs of the net cash flows of individual waste functions is another approach to gauging their costs over the planning period, as indicated in Table 30. The PVs are indicators of the total costs of each component in each CA. Note that the proportions attributed to the PVs are identical to those shown in Table 29 for their equivalent AICs.

Table 30: Comparing waste function costs relative to the PVs of net cash flows

$ million; 5% discount rate	CA					
Waste function	CA 1	CA 2	CA 3	CA 4	CA 5	Combined CA
Separate collection of recyclable material	24.6	6.8	2.8	1.5	0.6	36.4
Sorting of separately collected material	10.5	2.6	1.1	0.5	0.1	14.8
Collection of residual waste	93.2	26.6	11.1	5.5	1.5	137.9
Composting of green waste	7.8	2.9	1.6	0.7	0.5	13.5
Landfill	56.9	14.2	5.7	2.8	0.6	80.2
Total municipal waste	193.1	53.2	22.2	11.1	3.3	282.8

Table 31 summarizes the AICs for each function calculated as the unit cost per tonne of material managed.

Table 31: AICs per tonne of waste managed by each function

$/tonne; 5% discount rate	Function costs defined as the AIC per tonne of waste managed by each function AIC per tonne defined as the actual cost per tonne of material managed					
Waste function	CA 1	CA 2	CA 3	CA 4	CA 5	Combined CA
Separate collection of recyclable material	59.3	65.8	68.6	71.0	156.3	62.2
Sorting of separately collected material	25.4	25.4	25.4	25.4	25.4	25.4
Collection of residual waste	31.4	35.8	37.3	36.9	51.5	32.9
Composting of green waste	67.4	99.5	134.4	126.4	424.1	82.4
Landfill	19.2	19.2	19.2	19.2	19.1	19.2

6 Approaches to estimating residential waste management tariffs

The analysis of unit costs to this point has been based entirely on municipal waste quantities measured in tonnes. This chapter outlines three approaches to calculate residential waste management tariffs, two based on AIC analysis and the third on TA techniques. Each approach results in different revenue flows, unit costs, and indicative tariffs. Indicative tariffs are calculated per citizen. The PVs of the two AIC-based approaches are identical and that of the TA-based approach, while not identical, can realistically be taken to cover system costs in full. The approaches and their implications for unit costs, revenue allocations, and indicative tariffs are described in Sections 6.1, 6.2, and 6.3, respectively. They are compared in Section 6.4.[101]

Note that the chapter refers to 'indicative tariffs' rather than simply to 'tariffs'. Reasons for this are as follows:

- Unit costs (per tonne, citizen or household) referred to do not include costs such as value added tax (VAT). VAT is commonly levied on municipal charges. When levied, it should be treated as a cost in preparing affordability and financial sustainability analysis (Section 6.6).
- The unit cost approach to tariff setting does not necessarily comply with a country's legal requirements or government policy on cost recovery and tariffs.

The unit costs calculated are, nevertheless, indicative of the tariff levels necessary to cover waste costs in full in any year (but exclusive of any taxes or charges added by the government).

6.1 Calculating indicative tariffs per capita as an extension of the AIC per tonne approach

This approach to calculating tariffs per capita[102] is practically the same as that outlined to this point, where waste quantity is used as the physical base for calculating the AIC and for allocating costs over the planning period via the annual revenue requirement. The only difference is to divide the annual revenue requirement by the annual population to calculate indicative annual tariffs per capita.

The steps taken to calculate indicative residential tariffs using this approach are as follows:

1. Establish the annual net cash flow (investment costs + operational costs – residual asset value) and calculate its PV.
2. Establish the relevant waste[103] flow and calculate its PV.
3. Divide the PV of the net cash flow by the PV of the waste flow to calculate the AIC/tonne of waste generated.
4. Multiply the annual waste flow by the AIC/tonne to define an equivalent annual revenue requirement.
5. Divide the annual revenue requirement by the annual population to calculate indicative annual tariffs per capita.[104]

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[101] Note that Sections 6.1, 6.2, and 6.3 relate to costs only. Product sales and their effects on system net revenues are considered in Chapter 7.

[102] Or per household.

[103] Or material flow.

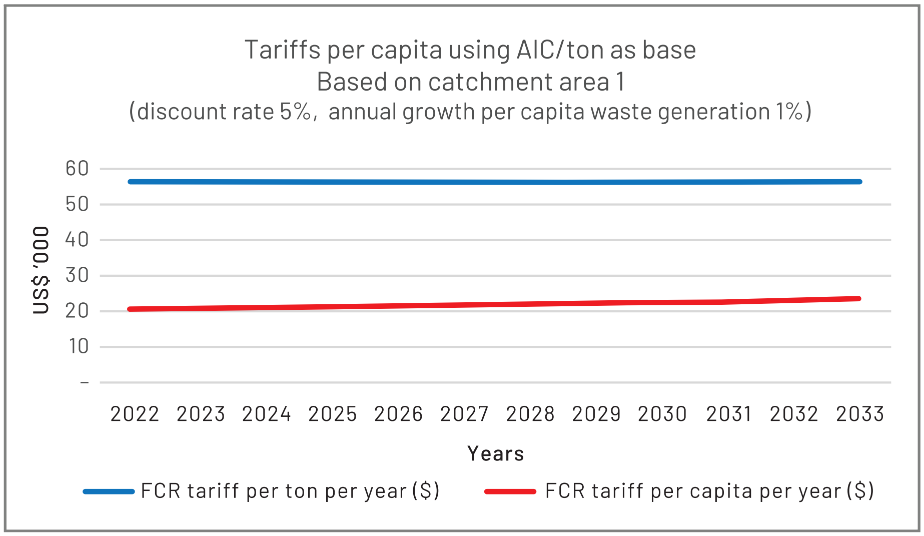
[104] Note: The indicative annual tariff per person is equivalent to the AIC per tonne multiplied by the waste generation per capita in each year.

Annual per capita charges estimated this way account for any projected changes over the planning period in both waste generation per capita and population numbers (both of which typically increase the quantity of waste generated annually). The unit cost per tonne of waste—the AIC—remains constant over the assessment period, whereas fees per capita (or households) increase with rising waste generation per capita. The approach is the most versatile of the three approaches described in this and the following two chapters as it can account for both a rising population and rising waste generation per capita.

The approach is suited to systems and tariff planning when realistic information is available on projected service demand (population growth and waste generation per capita) and on planned system capacity utilization constraints (for example, the design capacities of collection vehicles or sorting plant are sufficient to meet the projections of rising waste generation per capita and population).

Figure 15 shows the outcomes of analysis to define tariffs per capita. It relates to CA 1, which has a population of 1 million (assumed to remain constant over the analysis period) and a starting level of waste generation of 367,826 tonnes, projected to grow at 1 percent per capita per year over the planning period. An AIC of $56/tonne of waste generated is calculated by dividing the PV of the net cash flow ($193 million) by the PV of the waste generation flow (3.43 million tonnes). This is the constant horizontal blue line shown in the chart.

Figure 15: Tariffs per capita calculated using AIC per tonne as base



The AIC per tonne of waste generated is used to calculate the annual revenue requirement, which is the product of the AIC per tonne and annual waste quantities in tonnes. The PV of the annual revenue requirement is then identical to that of the net cash flow. The annual revenue requirement is then divided by the annual population (held constant over the planning period) to give a starting indicative tariff of $23/capita in 2022, rising to $26/capita in 2033 (indicated by the red line on the chart). The rise in the tariff profile results from increasing waste generation per capita (see also Table 32). The approach leads to lower tariffs in earlier years and to higher tariffs in later years, reflecting the user pays principle (rising waste quantity generated per capita).

Figure 15 also illustrates that the unit cost per tonne of waste managed (the AIC) is constant over time. Annual tonnage-based user charges would be calculated as the product of the quantity of waste generated and the fixed (AIC) cost per tonne of waste generated.[105]

Table 32 summarizes the equivalent AICs per tonne of waste generated and the indicative tariff ranges per citizen over the planning period for each CA and waste management component. Note that the AICs per tonne and tariffs per citizen for each CA sum to the totals for the combined system. This is because the AICs and tariff ranges for each waste function are calculated against the same base (tonnes per total waste generated and total citizen numbers receiving services).

Table 32: Unit costs per tonne and per capita: calculations based on AIC per tonne of waste generated

$; 5% discount rate	CA					
Waste function	**CA 1**	**CA 2**	**CA 3**	**CA 4**	**CA 5**	**Combined CA**
Combined system						
AIC per tonne	56.4	62.1	64.9	64.6	97.5	58.6
Tariff per citizen	20.7–23.1	22.8–25.7	23.9–26.6	23.8–26.5	35.9–40.0	21.5–24.0
Separate collection						
AIC per tonne	7.2	8.0	8.3	8.6	18.9	7.5
Tariff per citizen	2.6–2.9	2.9–3.3	3.1–3.4	3.2–3.5	7.0–7.8	2.8–3.1
Sorting plant						
AIC per tonne	3.1	3.1	3.1	3.1	3.1	3.1
Tariff per citizen	1.1–1.3	1.1–1.3	1.1–1.3	1.1–1.3	1.1–1.3	1.1–1.3
Residual waste collected						
AIC per tonne	27.2	31.1	32.3	32.0	44.6	28.6
Tariff per citizen	10.0–11.2	11.4–12.7	11.9–13.3	11.8–13.1	16.4–18.3	10.5–11.7
Green waste composted						
AIC per tonne	2.3	3.4	4.5	4.3	14.3	2.8
Tariff per citizen	0.8–0.9	1.2–1.4	1.7–1.9	1.6–1.8	5.3–5.9	1.0–1.1
Landfill						
AIC per tonne	16.6	16.6	16.6	16.6	16.6	16.6
Tariff per citizen	6.1–6.8	6.1–6.8	6.1–6.8	6.1–6.8	6.1–6.8	6.1–6.8

6.2 Calculating indicative tariffs per capita using an AIC per capita approach

An alternative approach to estimating an indicative tariff per capita is to calculate it directly by dividing the PV of the net cash flow by the PV of the flow of service users, giving a constant AIC per capita. Applying the AIC per capita to the resident flow then defines an annual revenue requirement from which a variable charge per tonne is calculated which declines with increasing waste generation. The annual revenue requirement has a PV equal to that of the net cash flow and allocates costs proportionally to resident numbers over the planning period. The approach is almost a mirror image of the first approach described above.

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[105] The analysis assumes that adequate plant equipment capacity requirements are built into the system design.

The steps involved are as follows:

1. Establish the annual net cash flow.
2. Define the annual number (flow) of resident users over the planning period and calculate its PV.
3. Calculate the AIC per capita: divide the PV of the net cash flow by the PV of the resident flow.
4. The AIC per capita is the constant indicative tariff per citizen over the planning period.
5. Define the annual revenue requirement: multiply resident numbers by the AIC per capita.
6. The PV of the annual revenue requirement is equal to that of the net cash flow.
7. Divide the annual revenue requirement by the waste flow to define the variable unit costs per tonne of waste generated over the planning period.

Figure 16 illustrates outcomes from the approach. It shows the constant AIC of $21.8 per capita and a declining revenue per tonne, from $59.2/tonne to $53.1/tonne. The decline in revenue per tonne is a function of the financial dynamics:

- The annual revenue required is derived from the constant AIC per capita over the planning period. Users pay the same tariff regardless of the amount of waste generated per citizen.
- The revenue generated each year is fixed per capita.[106]
- Consequently, as the quantity of waste generated rises revenue per tonne falls.

Figure 16: AIC per capita tariff and unit cost per tonne based on AIC per capita approach

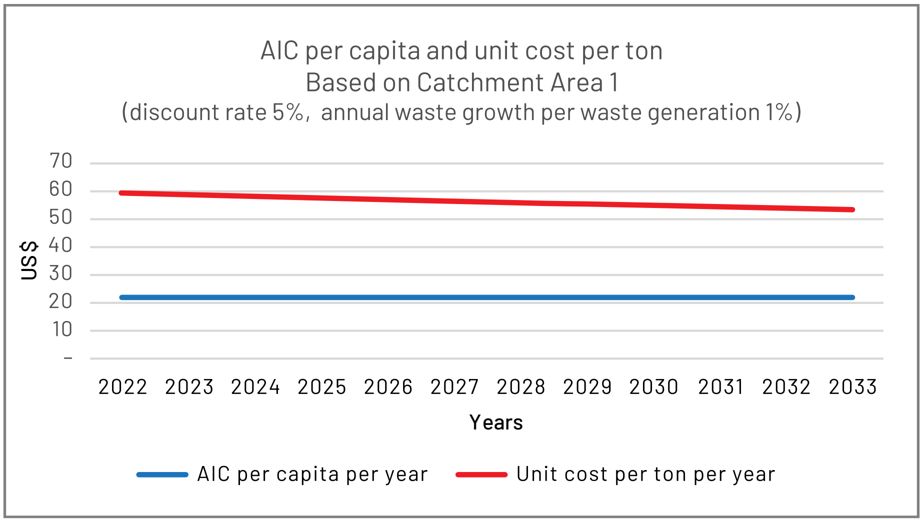

Figure 17 compares the constant AIC per capita tariff (as highlighted above in blue) with the variable tariff per capita from Section 6.1 and illustrated in Figure 16.[107]

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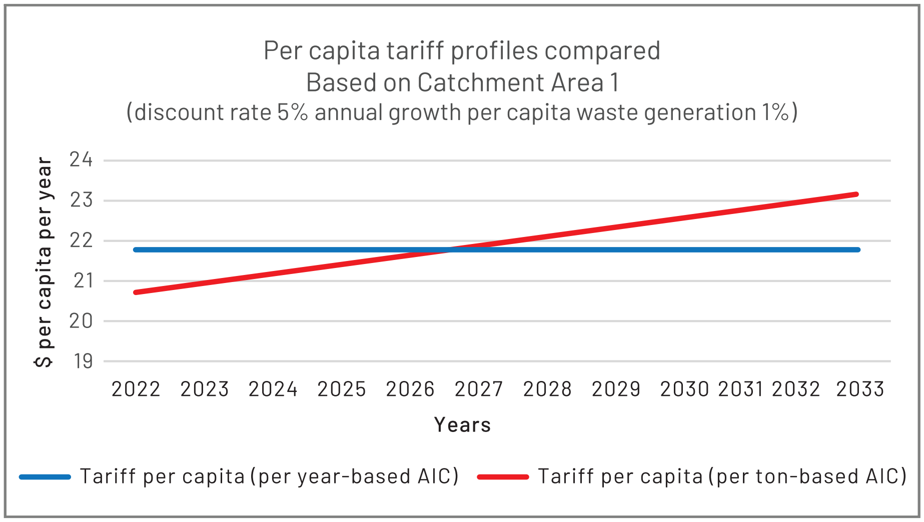
[106] Note that the AIC per capita is constant whether or not the population served is projected to remain constant or to rise over the planning period.

[107] Note the scale differences between Figures 16 and 17.

Figure 17: Comparing per capita tariff profiles for two AIC approaches



The fixed annual tariff per capita profile (shown in blue) results in all residents being charged the same amount over the planning period. The AIC per capita is $21.8. The variable tariff profile from Figure 17 starts from a lower bound of $20.9 per resident and rises to $23.1 per resident in the final year of the planning period. The PVs of the two revenue streams are identical and each covers costs in full.

The difference is that the AIC per capita approach relates only to resident numbers and does not consider changes in per capita waste generation. That is, system costs are allocated pro rata to the number of citizens receiving services each year. The AIC per tonne approach allocates system costs pro rata against waste quantities, the outcome of which is that tariffs start at a lower rate and become progressively higher with rising per capita waste generation.

The revenue requirement is allocated pro rata to the total number of residents served. Charges per capita estimated this way reflect variations in population numbers but do not account for variations in waste generation per capita. Residents pay the same charge each year even though the amount of waste they generate is rising; this means that residents in earlier years effectively subsidize residents in later years. It also means that the amount of revenue collected per resident reflects a declining amount of revenue per tonne of waste managed (as rising per capita waste generation is not matched by rising charges to users).

6.3 Traditional accounting approach to tariff setting

A third approach based on TA concepts is often used for setting tariffs in a specific year with only limited consideration given to future service demand or capacity constraints. But it is also commonly used for assessing existing services or planning new ones over time.

The net cash flow on which the analysis is based is defined as the sum of the following accounting costs:[108]

- Net Cash Flow = Operating Costs + Depreciation + Return on Investment (ROI)

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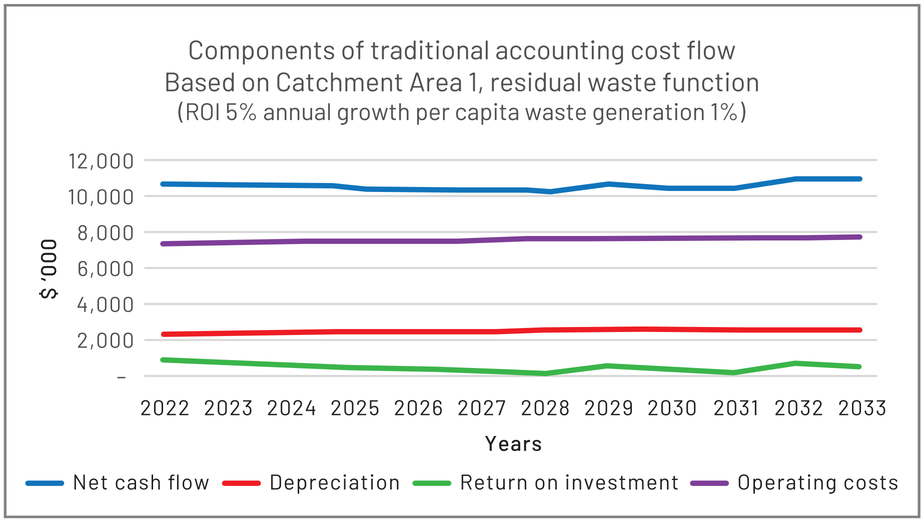
[108] Note that the three parameters (annual operating costs, depreciation, and ROI) are the accounting equivalents to the parameters used to calculate the AIC (annual operating costs, investment costs less residual value, and the discount rate).

The net cash flow defines the annual revenue requirement from which tariffs are calculated directly. Operating costs are same as the AIC analysis and depreciation and ROI are each derived from investment costs as per the AIC analysis. The components of the net cash flow are illustrated in Figure 18.

Figure 18: Components of the TA cost flow



The annual domestic tariff is calculated by dividing the net cash flow (which is also the annual revenue requirement) by the number of residents (or households).

- Tariff Per Resident = [Depreciation + Return on Capital + O&M Costs] / [Number of Residents]

The equivalent revenue requirement per tonne of waste is calculated by dividing the annual revenue requirement by the quantity of waste generated each year. That is,

- Revenue Per Tonne = [Depreciation + Return on Capital + O&M Costs] / [Tonnes of Waste]

Depreciation (the return of investment) is usually calculated annually for each asset by dividing its initial (non-depreciated) value by its projected economic life. The annual rate of ROI is calculated by multiplying the average value[109] of depreciated assets by the rate of return.[110]

A key factor to note is that the revenue flow is erratic. This results from the ROI falling as the value of the asset base on which it is calculated falls (the ROI effect[111]). The ROI effect is seen in Figure 19, both in the ROI cost and the net cash flow profiles. It is shown in more detail in Figure 20.

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[109] The average value of a depreciated asset is taken to be the average of the opening and closing values in a specific year (that is, the average of the asset's value before and after depreciation is recognized in that year).

[110] The required ROI is taken to be the same as the discount rate employed in the AIC approach.

[111] The ROI effect results from the falling accounting value of an asset as it becomes progressively depreciated. Once an asset becomes fully depreciated it is replaced and the investment, depreciation, and ROI cycle starts again.

Figure 19: The ROI effect

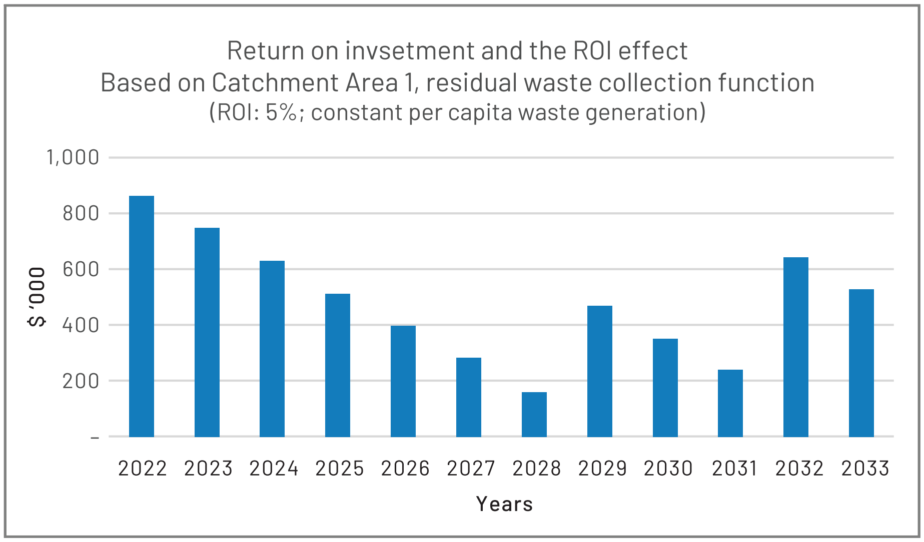
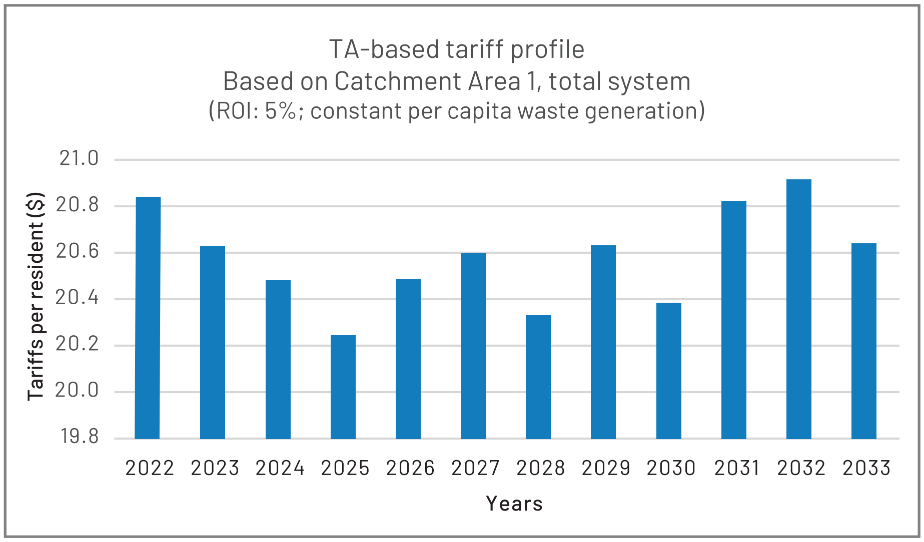


Figure 20 illustrates the erratic profile of the residual waste collection component of the CA 1 waste management system. Note that the figure is based on a scenario of both a constant population and a constant rate of waste generation per capita over the planning period. This has been done to illustrate the ROI effect which can otherwise be disguised if other waste management dynamics are in play.

Figure 20: TA-based tariff profile



It is important to note that investment costs allocated via the depreciation provision are determined purely by time[112] and not by the level of demand for the services (waste generated or population served). In a situation of projected rising population or per capita waste generation (or both), the approach results in higher costs per tonne or per person in earlier years than in later years. Not only does this conflict with objectives such as the user- and polluter-pays principles, it also defeats the aim to

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[112] The value of an asset is typically recovered by the depreciation provision in equal amounts over the asset's life and is unrelated to population size or waste generation per capita.

increase tariffs over time as services become increasingly more affordable through income growth.

Figure 20 illustrates the TA-based tariff profile estimated for the total CA 1 system. It is also calculated for a scenario of constant population and constant waste generation per capita.

Waste management costs consist primarily of fixed investment and operational costs. Growing populations and rising waste generation per capita therefore lead to falling residential tariffs and unit costs per tonne over time.[113] This, coupled with the ROI effect, makes cost recovery and tariff planning over time based on the TA approach a complicated and uncertain exercise.

Summary of problems with the TA approach:

- The approach implicitly assumes that *accounting* costs for one year should be covered by user charges in that year (for example, investment costs are allocated equally over time by the depreciation provision).
- Annual revenue requirements and tariffs calculated from them are unrelated to the level of service demand (waste quantity collected) in each year.
- Annual tariff and revenue flows can be erratic over time (ROI effect).
- Tariffs per capita fall over time with rising resident numbers as fixed annual accounting costs are spread pro rata over an increasing number of residents.
- Tariffs are not responsive to rising levels of waste generation per capita over time.
- Unit costs per tonne are erratic and fall relative to rising waste quantities over time.

The above constraints suggest that the approach should not be used for medium- to long-term strategic and financial planning. Refer to Annex 4 for further details on the TA approach.

6.4 Comparison of AIC and TA approaches

Both the AIC per tonne and the TA approaches define an annual revenue flow that covers total costs in full. They differ in the way investment costs are recognized. This is in turn reflected in the way annual revenue requirements are defined and in the tariff profiles created from them. To recap, the AIC per tonne approach is based on the estimated annual investment costs, the residual value of the assets created by the investments, annual operating costs, and the discount rate used to discount future cash flows to their PVs. The TA approach is based on depreciation of the assets created by the investments, the financial return on those investments, annual operating costs, and the relevant rate for calculating the ROI (taken to be equal to that of the discount rate). Identical revenue streams are generated in PV terms, but the timing of the revenue flows that give rise to those PVs is significantly different.

The TA approach leads to erratic and falling tariffs over the planning period whereas the AIC approach results in progressively rising tariffs consistent with rising populations and increasing waste generation per capita. Note, however, that the AIC approach depends critically on the availability of accurate data on current and projected population numbers, per capita waste generation, and per capita incomes.

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[113] It is assumed that demand for the services remains within the design capacity constraints of the system.

6.5 Value of AIC analysis to waste systems analysis and tariff planning

The AIC approach to calculating unit costs, tariffs, and the annual revenue required to cover system costs is versatile and readily applicable to many situations. It can provide powerful insights into system costs and enables cost recovery revenues to be fairly allocated against service use. A key feature is that future population and waste generation conditions are recognized today when estimating unit costs, annual revenue requirements, and tariffs for tomorrow. Costs are covered in full, and a steady and predictable revenue stream is generated over the planning period.

Outcomes of the analysis can be used to answer several questions: are the proposed services affordable to users and the municipality; are they financially viable; is external grant funding needed; does the scope and scale of the system envisaged need to be reexamined?

6.6 Affordability and financial sustainability

6.6.1 Affordability

Affordability relates to the ability of users to pay for services. The affordability of municipal waste services is the maximum share of average monthly income that households should realistically be expected to spend on waste management services (the affordability constraint). Affordability can also be expressed as the proportion of waste management costs in total average household expenditure. Using household expenditure rather than household income can give more accurate information, as household income data rarely capture all sources of revenue. This is particularly the case in less developed countries, where informal activity can contribute a substantial share of household income.

Global good practice is to set household waste tariffs up to a threshold value equivalent to 1 percent of average household income (sometimes within a range of 0.75 percent to 1.5 percent). This effectively sets an upper limit (or constraint) on the share of average per capita or household income to be allocated for waste services. Using this yardstick, the assumption is made that charges set up to 1 percent of average household income will be affordable to most households, including those with incomes lower than the average. The approach does not mean that each household should be charged 1 percent of its specific household income or that charges should be set at 1 percent of the lowest levels of household income.

Note that the 1 percent yardstick is a particularly useful parameter against which to gauge the affordability of current tariffs.

Calculating the affordable tariff per capita (or per household) depends on having reliable estimates of average per capita income (and of average household size if tariffs are to be charged per household[114]). The affordable tariff per capita or per household is simply calculated as 1 percent of average per capita or household income.[115]

Understanding the reliability and limitations of the data used in making affordability decisions is crucial to the future viability of the services dependent on them. Evidence shows that a project which is affordable in one part of a country may not be

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[114] Average household size refers to the average number of occupants per household.

[115] Charges may not be affordable to some vulnerable households on particularly low incomes. Such households should qualify for social assistance.

affordable in another.[116] This reveals the need for a thorough socioeconomic analysis to define the scope, scale, costs, and financing of municipal or regional waste services. This is necessary if the services are to be appropriate, affordable, and financially viable.

An example from a recent analysis undertaken at the country level in a low- to middle-income economy illustrates the process:

- Average annual income per capita per year: $2,100
- Current waste tariff per capita per year: $3
- Current waste tariff as a % of average income: 0.14 percent
- Potential tariff at 1 percent of average per capita income per year: $21.

An implication of this result is that current tariffs could be raised seven times before the affordability threshold is reached. Although simplified, the example demonstrates the analytical process. In practice, the analysis focuses on the specific financial conditions at the project location and may possibly differentiate tariffs between urban and rural areas. The significance of this for systems development and financial planning can be seen in the context of the affordability of the charges.

Note that financial conditions in the area of the analysis may not be appropriate for defining domestic waste management tariffs as outlined above. The approach implicitly assumes that income distribution in the study area lends itself to using average income per capita as the base for estimating waste tariffs. The extent to which it is conducive can be considered in the context of the Gini coefficient.

The Gini coefficient is a commonly used measure of income distribution: the higher the Gini coefficient the greater the gap between the incomes of a country's richest and poorest people.[117] The Gini coefficient is important because it helps identify high levels of income inequality. The coefficient can hypothetically range between a Gini score of 0 (absolute equality with every person earning the same amount) to a Gini score of 100 (absolute inequality whereby one person earns all the income in a nation and the rest earn zero).

The World Bank publishes Gini coefficients for most countries, which rise from a low figure of 25 (Slovenia, 2018) to a high figure of 63 (South Africa, 2014). The example above derives from a country with Gini coefficient of 36—a low coefficient indicating a high level of income equality and a perfect example for applying the affordability criterion. Countries with high Gini coefficients have high levels of income inequality for which the affordability approach is unlikely to be appropriate and for which alternative mechanisms for defining and implementing cost recovery systems for domestic waste services will be needed.[118]

6.6.2 Financial sustainability

The second constraint is the need to ensure the financial viability of the services. Financial viability means always having some cash in the bank. What happens if net cash flow in one year is negative (outgoings exceed incomings)? This depends on whether positive cumulative cash reserves at the start of the year are sufficient to offset any deficit for that year. Annual net cash flow is defined as annual cash in-

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[116] Note that when comparing the assessed affordable tariff with the proposed tariff, the tariff should reflect the full cost to be funded by users, including VAT or other supplementary charges if appropriate.

[117] https://worldpopulationreview.com/country-rankings/gini-coefficient-by-country.

[118] Examples can be found in the World Bank publication 'Bridging the Gap.'

flows minus annual cash outflows (money in and money out). A financial sustainability rule is therefore that cumulative net cash flow should be positive for all years. Cash inflows comprise user charges, municipal transfers, municipal taxes, grant funds, loan funds, private equity, and income from the sale of recovered materials. Cash outflows comprise investment expenditures, O&M expenditures, debt service obligations, contractual obligations to the private sector, and other such cash outlays.

The matter of financial sustainability only arises if the services are planned to be managed on a commercial basis, where proper budgeting and accounting procedures are put in place and funds are set aside to meet liabilities when they become due. Such a discipline is needed if waste services are to be efficiently maintained and financed over time. It does not mean that households should be charged for the full costs of the services—setting charges at rates that achieve partial cost recovery is common—but that the balance of costs to be funded by municipal transfers or other funding sources must be budgeted and accounted for accordingly in advance.

Many countries have introduced earmarked municipal taxes or charges to fund the operational costs of household waste services and quite commonly a mix of the two. Typically, though, cost recovery policy is incomplete. It is common for tariffs to be set to raise sufficient revenue to cover a specific funding objective (for example, to cover direct cash operating expenditures) but with the balance of cash outlays to be covered in an ad hoc and unbudgeted way from the municipal budget.

This situation was remarked upon in the South African Municipal Solid Waste Tariff Strategy, May 2012 as follows:

"If such an approach [a combination of property rates and user charges] is adopted it should be formalised, i.e., an explicit proportion of the rates revenue should be set aside for solid waste services based on a well-presented indication of the costs of public waste management services. At present, this combined approach is applied by many municipalities on an ad hoc basis as the general rates account is used to subsidise any deficit accruing on the solid waste account. This approach, where any deficit (whether coming from public or private services or simply from poor management) is automatically funded out of the rates account, provides no efficiency incentives and should not be regarded as an acceptable tariff structure."

6.6.3 Fixed and variable costs

Municipal waste management costs are largely fixed: costs incurred irrespective of the amount of waste collected or treated (within the constraints imposed by the installed capacity of the equipment being used). Fixed and variable costs cannot always be differentiated clearly, but typically fixed costs of municipal waste services constitute 60–80 percent of total costs, and the less technically advanced systems bear the larger share of fixed costs.

Fixed costs are recurring costs: payments related to time and regularity rather than to the quantity of waste collected or treated (for example, services such as lease costs, accounting and billing, the purchase and supply of waste containers, labor costs, maintenance costs, fuel costs, depreciation costs, utility bills, and insurance). They are costs that must be funded regardless of the amount of waste being collected or treated. Variable costs relate directly to the quantity of waste being handled: landfill gate fees are an example.

The high fixed cost component of municipal waste costs has important implications for waste charging schemes and other aspects of municipal waste management, such as for determining the costs avoided if a proportion of the residual waste flow is diverted to a separate recycling scheme.

6.6.4 Fixed costs and municipal waste charging systems

The traditional form of charging is to charge all households a single fixed fee regardless of the level of service used (the fee has no effect on the amount of waste put out for collection). It serves the objective of creating a largely stable and predictable revenue stream. In more recent years, some towns and cities began to introduce charges based *entirely* on the weight or volume of waste put out for collection, which is an incentive for households to reduce the amount of waste they generate and/or to increase the amount of waste separately set out for recycling.

The effect of a charging scheme based on users being charged a total fee per unit (for example, per kg) of waste collected is that a fall in the amount of waste presented for collection results in an equivalent fall in the amount of revenue collected. This outcome is perverse, as reducing the amount of waste collected leads to the avoidance of only the variable component of the total unit cost. The fixed cost component is unchanged and must still be covered by revenues. This outcome can be illustrated by a simple example.

Assume the following:

- A weight-based charging scheme based entirely on a fee per kg of waste collected
- Fixed costs are 70 percent and variable costs are 30 percent of the cost of total waste collected
- A container presented for collection contains 20 percent less waste by weight than it did last week.

The total cost of collecting the waste is 6 percent less than it was in the previous week. Why?

- 70 percent of the cost of emptying the bin is fixed (it remains the same as the week before)
- A 20 percent reduction in waste quantity results in a proportionate fall of 20 percent in the variable cost share (30 percent) of total costs (that is, 20% × 30% = 6%)
- The total cost does not fall by 20 percent but by the marginal cost reduction of 6 percent of the total
- The customer receives a 20 percent reduction in his/her bill
- Net revenue falls by 14 percent (a 20 percent saving to the customer minus 6 percent of variable cost avoided).

In summary, the cost structure of municipal waste services dictates that a stable revenue stream cannot be achieved if the charging mechanism depends entirely on a variable charge base (waste quantity or citizen-based charges). That is why hybrid charging schemes have evolved in recent years to combine a large fixed, non-service dependent component with a smaller variable service-dependent component based on the level of usage. The fixed fee reflects the recovery of costs already incurred in providing the services, regardless of whether a household uses them or not (fixed costs). The fixed fee is less a payment for using the service and more a payment for being provided with the opportunity to do so. The variable component refers to the actual costs avoided.

7 Revenue from sales of separately collected and sorted material

This section begins by setting out some of the commercial factors to consider when planning a separate materials collection and recycling scheme. The second part outlines an analytical approach to estimating the financial viability of such schemes.

7.1 Commercial considerations regarding separate collection of recyclable waste

A key objective of many local municipalities is to recover value from materials contained in the waste stream. Although separation at source is increasingly becoming a legal requirement, implicit in this is a desire to generate profits which can contribute to the costs of the wider waste management system. Waste management strategies typically include components to separately collect, sort, and market recyclable waste. The revenue projected from the sale of these materials has accordingly been included as part of the sources of funds proposed to finance municipal waste services.

The materials recovery and sales component is part of the total municipal waste management system, its costs form part of total system costs, and its sales revenues contribute to the total revenue needed to cover system costs in full. The materials recovery and sales system is assessed below from the perspective of a separate, stand-alone commercial entity. This is followed by a general commentary on the financial viability of material recovery schemes together with some summary notes to help guide decision-making in this area.

It should be remembered that collecting recyclable materials separately avoids the need to gather and dispose of them to landfill. That is, mixed waste collection and landfill disposal costs are reduced. These avoided costs should be fully recognized when assessing the net costs of the materials recovery system. But note that the full costs of service provision are not avoided if material is diverted from the residual waste stream to the separate collection of recyclable material. This situation arises because the fixed costs of waste services range from 60 to 80 percent of the full costs of service provision. Only the variable component of system costs is potentially avoidable. This is developed further in Section 7.3.2 and under the heading 'Residual waste collection costs avoided and credited to the separate waste collection service' in the same section.

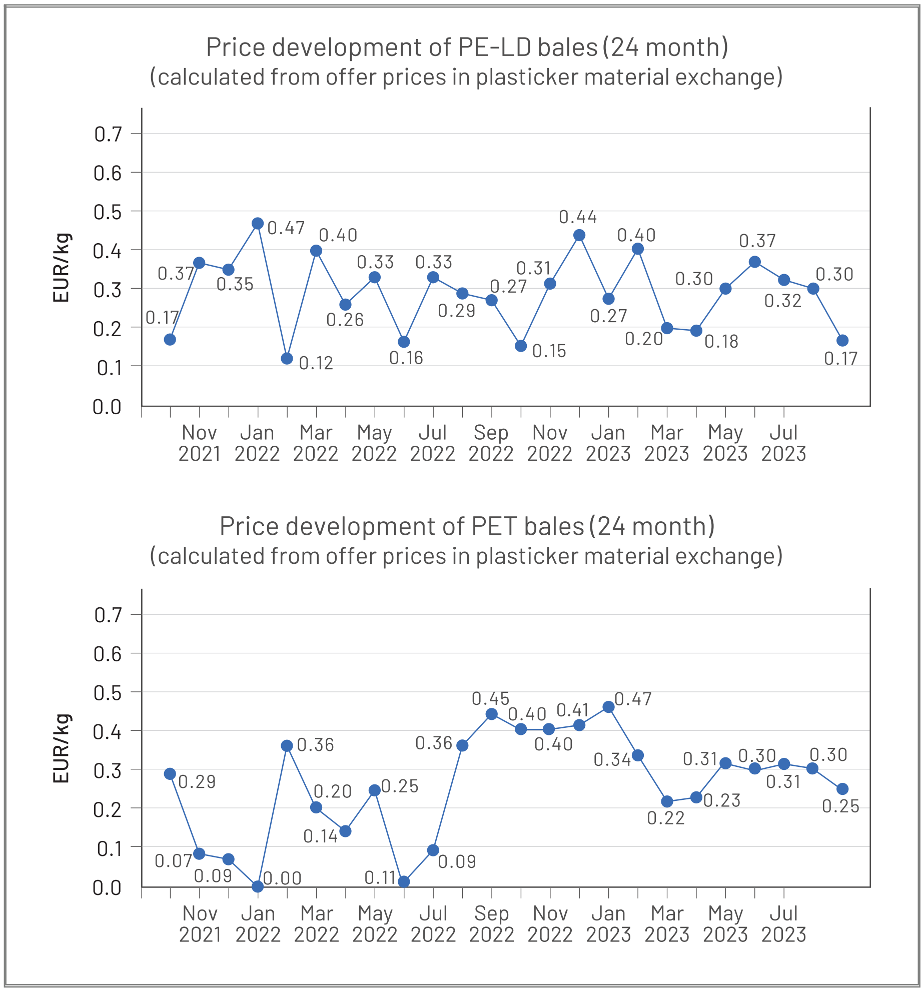
Revenue from the sale of recyclable materials is subject to two main risks: (a) the quantity of recoverable material in the separately collected waste and (b) the markets for the materials recovered. Unless driven by mandatory obligations, materials recovery systems should be implemented when there is a high level of confidence that (a) a realistic and predictable supply of recoverable material is available for collection and (b) proven markets exist for the recovered materials.

Concern over waste composition comes from an awareness that informal collectors can often retrieve a large share of the valuable material before it can be formally collected. If this is the case, then the material quantities on which the sorting plant capacity and the sales analysis are based may be unrealistic. This factor is crucial to the assessment of any materials recovery scheme. Data on the composition of the waste stream available for formal collection are generally poor.

Markets for materials recovered from municipal waste are often poorly developed, with assumptions on product markets, sales potential, and selling prices being speculative and uncertain. A reliable market analysis of the potential for recyclable material sales should be undertaken in the planning phase.

The prices of recyclable waste commodities also vary considerably over time. As an example, the following two charts show changes in average market prices for two of the most commonly recycled plastics in Germany over the last two years.

Figure 21: Variations in prices of waste plastics for PET and low-density polyethylene (LDPE) bales



Price development of PE-LD bales (24 month)
(calculated from offer prices in plasticker material exchange)

Price development of PET bales (24 month)
(calculated from offer prices in plasticker material exchange)

Importantly, it should be recognized that municipal waste management is a net cost activity. The extensive systems of waste material recovery found in wealthier countries today are a result of legislation that imposes strict and binding waste management targets on local authorities. As part of its program of measures to achieve these targets, the UK government currently levies a landfill tax of £97 ($125) on each tonne of waste disposed of to a landfill (in addition to the full cost recovery charges charged by the landfill operators). The tax acts as an incentive for municipalities to find waste treatment and disposal routes that are environmentally preferable to landfill. Placing a tax on landfill makes these alternative routes relatively more financially attractive. Municipal waste management is a net cost activity (as, in general, is the separate collection and sorting component).

The tax has led to a range of recycling, composting, and other waste treatment facilities being offered by private waste management firms as lower-cost alternatives to landfill. Firms are motivated by the opportunity to earn a profit on their investments. The cost of these services (including profit) is covered by the fees the firms charge municipalities for using them. These costs, in turn, are funded by charges municipalities levy on households and businesses. Municipalities rarely make a profit. Municipal authorities should not seek to establish waste treatment facilities in anticipation of creating incremental revenues for the municipality. Investment in such facilities should be made after thorough analysis of material availability, technical systems and costs, markets, prices, and risks.

Ideally, investments in separate collection and sorting should be made if the commercial conditions surrounding the investments are predictable and realistic: that the material input is available and market conditions demonstrate a viable market. That is, the venture is commercially sound and the commercial activities will break even.

7.2 Revenue and cost flows associated with product sales

The following analysis assesses the prospective financial performance of a separate material collection and recycling scheme. It draws on waste and material flows, revenue flows, and cost flows introduced in earlier chapters. It is based on a hypothetical waste CA defined by the combined populations of the five CAs. The analysis relies on material quantities, PVs, and unit costs calculated using the AIC approach.

The combined catchment has a population of 1.41 million residents and generates 6.6 million tonnes (PV of 4.8 million tonnes) of waste over the planning period. Residual (mixed) waste collected and landfilled is 5.7 million tonnes (PV of 4.2 million tonnes). The PVs and AICs of relevant waste and material flows are as follows:

- Residual waste collection costs of PV \$137.9 million and AIC of \$32.9/tonne of *residual waste collected*
- Separate collection costs of PV \$36.4 million and AIC of \$76.0/tonne *of material sold*
- Recyclable material sorting costs of PV \$14.8 million and AIC of \$31.0/tonne of *material sold* (recycled)
- Landfill costs of PV \$80.2 million and AIC of \$19.2/tonne of *waste disposed of to a landfill*
- Total material sales have a PV of \$29.1 million over the planning period and an average AIC of \$60.8/*tonne of material sold* (see Table 33 and analysis below).

Separately collected and sorted waste of 0.81 million tonnes (PV of 0.58 million tonnes) is divided into the sale of 0.67 million tonnes of recyclable material (PV of 0.48 million tonnes) and the disposal to landfill of 0.15 million tonnes of residual sorting waste (PV of 0.11 million tonnes).

7.3 Revenue flows

Two potential sources of revenue for funding a commercially viable municipal separate collection and recyclable sorting scheme are as follows:

- Revenue from the sale of recyclable material
- Revenue credited to the separate collection and sorting scheme from the costs avoided by the residual waste service (reduced volumes of waste collected and landfilled).[119]

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[119] Revenue credited to the separate material collection and sorting service for costs avoided by the residual waste service is considered following the analysis below of the direct costs incurred.

7.3.1 Revenue generated from the sale of recyclable materials

Recyclable materials collected are paper and card, plastic, and metal. The quantity collected, the quantities sorted and sold to recycling entities, the selling prices and revenues generated over the planning period are set out in Table 33. The data relate to a notional catchment defined by the combined data inputs and findings for the five catchments. Also shown are the average incremental revenues calculated per tonne of material sold. These show the contribution made to total revenue per tonne of each material type. Importantly, they enable unit revenues to be compared directly with unit costs when calculated as *costs per tonne of material sold*. Costs incurred in generating the sales revenue are covered in the Section 7.4.

Table 33: Parameters contributing to revenue analysis

Material type	Separately collected materials	Total material sold	Sales price	Revenue		
				Total revenue from sales	PV of revenue from sales	AIC of total material sold
	Million tonnes	Million tonnes	$/tonne	$ million	$ million	$/tonne[120]
Paper and card	0.44	0.35	50	17.5	12.6	26.2
Plastics	0.23	0.18	100	18.2	13.1	27.3
Metals	0.06	0.05	100	4.8	3.5	7.2
Total	**0.73**	**0.58**		**40.5**	**29.1**	**60.8**

The average AIC *per tonne of material sold* is $60.8. It is the sum of the AICs calculated for each material type. They can be summed in this way because of their common material base (tonnes of total material sold). The figure can also be calculated by dividing the PV of total sales revenue ($29.1 million) by the PV of total recyclable material sales (0.48 million tonnes[121]), giving an average revenue of $60.8/tonne of material sold.

7.3.2 Residual waste collection costs avoided and credited as revenue to the separate waste collection service

The costs avoided by reducing the quantity of residual waste collected and landfilled constitute a potential revenue credit to separate collection and sorting activities. It can be argued that the revenue credited should reflect the full unit cost per tonne of residual waste service.[122] This assumption can be wrong, with the costs avoided frequently being confined to the variable component of total costs[123] (of which the avoidance of landfill costs is an example). If the analysis is being prepared for a pre-existing system into which a recyclable material collection and sorting service is to be introduced, then it is only the variable component of current costs that is affected by diverting waste from the residual waste service to the new recycling service.[124]

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[120] AICs in the final column of Table 33 are calculated as the PV of revenues from sales (for example, $12.6 million from paper and card sales) divided by the PV of the total quantity of material sold (0.48 million tonnes), giving an AIC of $26.2/*tonne of total material sold.*

[121] Section 7.2 refers (final paragraph).

[122] That is, the avoided cost should be calculated as the quantity of waste diverted to separate collection multiplied by the full cost per tonne of providing the residual waste services.

[123] Please refer to Section 6.6.3 for an outline of fixed and variable costs in municipal waste services.

[124] If an entirely new waste management service is to be introduced, and services are to be prepared for both residual waste collection and secondary recyclable material collection, then it is unlikely that the issue of avoided costs between the two services will arise. The services will be designed to achieve optimal outcomes for route design, service frequency, equipment capacity requirements, and financial commitments. The question of avoided costs is only likely to arise if, in the future, major changes to current material flow arrangements are planned.

As noted in Section 6.6.3, fixed costs typically constitute 60 to 80 percent of the total costs of municipal waste services, and less technically advanced systems are characterized by larger shares of fixed costs. The following analysis assumes that fixed costs are 70 percent of total costs and variable costs 30 percent.

The total amount of waste diverted from the residual waste flow of 0.81 million tonnes has a PV of 0.58 million tonnes. The full cost of managing this quantity of residual waste is PV $11.1 million (PV 0.58 million tonnes × $19.2/tonne[125] of waste landfilled). Of this, fixed costs are PV $7.8 million (70 percent) and variable costs PV $3.3 million (30 percent). The PV of the costs potentially avoided is therefore $3.3 million which, expressed per tonne of material sold, is equivalent to a revenue of $6.9/tonne (PV $3.3 million / PV 0.48 million tonnes).

In summary, the costs potentially avoided by the residual waste collection service of PV $3.3 million are equivalent to a revenue of $6.9/tonne of material sold.

7.4 Costs incurred in generating the sales revenue

Costs relevant to sales revenue are as follows:

- The cost of separate waste collection and sorting plant operations
- The cost of sorting plant residues disposed of to a landfill.

7.4.1 The costs of separate waste collection and sorting plant operations

The costs of separate collection over the planning period have a PV of $36.4 million and an AIC of $76.0/*tonne of material sold*. Sorting costs have a PV of $14.8 million and an AIC of $31.0/*tonne of material sold*. As the AICs are calculated using a common base (tonnes of material sold), they can be added together. The combined total cost of separate collection and sorting therefore has a PV of $51.2 million, with an AIC of $107.0/tonne of material sold. These figures are calculated as follows:

- The PVs of the net cost cash flows for separate collection and sorting are $36.4 million and $14.8 million, respectively.
- The AICs of the two functions are calculated by dividing their PVs by the PV of the quantity of material sold (0.48 million tonnes). That is, $36.4 million / 0.48 million tonnes (= $76.0/tonne sold) and $14.8 million / 0.48 million tonnes (= $31.0/tonne sold).
- The totals combined are $51.2 million (PV) and an average of $107/tonne sold (AIC).[126]

Equivalent outcomes (rounded) for each CA are set out in Table 34.

7.4.2 The unit costs of landfill

The total amount of waste landfilled over the planning period is 5.7 million tonnes (PV 4.2 million tonnes). The total cost of landfill operations has a PV of $80.2 million and an AIC per tonne of waste landfilled of $19.2/tonne ($80.2 million / 4.2 million tonnes).

The total quantity of waste separately collected and sorted is 0.82 million tonnes (PV 0.59 million tonnes). Of this, 0.67 million tonnes (PV 0.48 million tonnes) is sold for recycling and 0.15 million tonnes (PV 0.11 million tonnes) consists of sorting plant residues disposed of to a landfill.

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[125] See Section 7.2.

[126] As the two AICs are calculated from the same base (tonnes of waste sold) they are additive, giving a total AIC for the two functions of $107/tonne sold.

Table 34: AICs per tonne of waste managed by each function

$/tonne; 5% discount rate	Function costs defined as the AIC per tonne of recyclable material sold					
Recycling function	CA 1	CA 2	CA 3	CA 4	CA 5	Combined CA
Separate collection of recyclable material						
$ PV (million)	25	7	3	1.5	0.6	36
$ AIC/tonne sold	72	80	84	87	191	76
Sorting of separately collected material						
$ PV (million)	11	3	1	0.5	0.1	15
$ AIC/tonne sold	31	31	31	31	31	31
Combined totals						
$ PV (million)	35	9	4	2	1	51
$ AIC/tonne sold	103	111	115	118	222	107

Waste generated from the sorting plant is 2.6 percent of total waste landfilled (PV 0.11 million tonnes / PV 4.2 million tonnes). The share of total landfill costs attributable to sorting operations is therefore PV $2.1 million ($80.2 million × 2.6 percent).

As the AICs calculated above for the cost and revenue analysis are defined per tonne of material sold, the unit costs of the landfill component should be defined in the same terms. This is done by dividing the PV of the landfill costs incurred by the sorting plant (PV $2.1 million) by the PV of the quantity of material sold (0.48 million tonnes). This gives a unit cost of $4.4/tonne of material sold and compares to a cost of $19.2/tonne of the sorting waste landfilled. The difference between the two AICs arises from the PV of the landfill costs (PV $2.1 million) being allocated across two different bases: the larger quantity of recyclable material sold (0.48 million tonnes) and the smaller quantity of waste material landfilled (0.11 million tonnes). The calculations are as follows: PV $2.1 million / 0.48 million tonnes = $4.4/tonne of recyclable material sold; and PV $2.1 million / 0.11 million tonnes of material landfilled = $19.2/tonne of waste landfilled.

In summary, the PV of landfill costs attributable to the separate collection and sorting activity is $2.1 million and is equivalent to an AIC of $4.4/tonne of material sold.

7.4.3 Total costs incurred in generating the sales revenue:

Total costs incurred in generating the sales revenue are as follows:

- Separate waste collection: PV $36.4 million; AIC $76.0/tonne of material sold
- Sorting plant operations: PV $14.8 million; AIC $31.0/tonne of material sold
- Sorting plant residues to landfill: PV $2.1 million; AIC $4.4/tonne of material sold
- Total costs: PV of $53.3 million and an AIC of $111.0/tonne of material sold.

7.5 Summary of material sales outcomes

Table 35 summarizes the findings. Total revenue of PV $32.4 million (product sales of PV $29.1 million and avoided residual waste and disposal costs of PV $3.3 million) covers 61 percent of costs of PV $53.3 million, leaving a deficit of PV $20.9 million to be funded from other revenue sources.

Expressed in unit terms, the average revenue generated from product sales plus credits for avoided costs by the residual waste collection and disposal service[127] of $67.7/tonne cover 61 percent of the total unit cost of $111.4/tonne of material sold. The balance of $43.7/tonne of material sold must be funded from other sources.

Table 35: Summary of revenues and costs associated with product sales

	PV	AIC	
	$, millions	$ per tonne of material separately collected and sorted	$ per tonne of material sold
Revenues		Relative	Actual
Total of product sales	29.1	49.8	60.8
Collection and disposal costs avoided by residual waste operators	3.3	5.6	6.9
Total revenue	32.4	55.4	67.7
Costs			
Separate waste collection	36.4	62.3	76.0
Sorting plant operations	14.8	25.4	31.0
Sorting plant residues disposed of to landfill	2.1	3.6	4.4
Total costs	53.3	91.3	111.4
Net revenue	–20.9	–35.9	–43.7

The costs and revenues of recyclable collection, sorting, and sales can be placed in perspective by comparing them with the costs of residual waste collection and disposal.

- The full cost of residual waste collection and disposal over the planning period is PV $218.2 million (waste collection: PV $137.9 million; disposal: PV $80.2 million). The quantity of waste collected and disposed of is PV 4.19 million tonnes, giving a combined unit cost of $52.1/tonne of residual waste collected (PV of $218.2 million / 4.19 million tonnes). The unit cost is allocated as $32.9/tonne residual waste collected and $19.2/tonne of residual waste landfilled.[128]
- The cost of collecting and sorting recyclable material for sale is PV $53.3 million, allocated as separate collection: PV $36.4 million; sorting plant operations: PV $14.8 million; sorting plant residues disposed of to a landfill: PV $2.1 million. The quantity of recyclable material collected is PV 0.58 million tonnes, giving a unit cost of $91.9/tonne of total recyclable material collected (PV of $53.3 million / 0.58 million tonnes).
- The unit cost of recyclable material collected, sorted, and sold is $91.9/tonne, which is significantly more than the unit cost of residual waste collection and disposal of $52.1/tonne ($32.9 collection and $19.2 disposal).[129] After factoring in sales revenues of PV $32.4 million,[130] the net cost of recyclable sales to the municipal waste system is PV $20.9 million

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[127] Note that revenues include credits of PV $3.3 million for costs avoided by the residual waste collection and disposal service.

[128] The assumption is made that all residual waste collected is landfilled.

[129] The unit costs of the two functions can be realistically compared as they both involve the collection of municipal waste and its final disposal either to landfill or to recycling plants.

[130] Including collection and disposal costs of PV $3.4 million avoided by residual waste operators (refer Section 7.3.2).

- The net cost of PV $20.9 million constitutes an *incremental* increase in current total domestic waste system costs. It represents a net cost of $35.9/tonne of recyclable material collected (PV $20.9 million / PV 0.58 million tons) or $4.3/tonne of total waste generated (PV $20.9 million / PV 4.83 million tonnes), refer to Table 36.
- These outcomes should be considered within the context of the comments made in Section 7.1.

Table 36 summarizes the total cost and revenue flows for the combined waste management system consisting of CAs 1 to 5.

Table 36: Summary of cost and revenue flows estimated for the combined system

	PV	AIC relative	AIC actual
	$, millions	$ per tonne of waste generated	$ per tonne of material separately collected and sorted
Revenues from recyclable material sales			
Total from product sales	29.1	6.0	49.8
Collection & disposal costs avoided by residual waste operators	3.3	0.7	5.6
Total revenues	32.4	6.7	55.4
Costs of recyclable material sales			
Separate waste collection	36.4	7.5	62.3
Sorting plant operations	14.8	3.1	25.4
Sorting plant residues disposed of to landfill	2.1	0.4	3.6
Total recyclable material costs	53.3	11.0	91.3
Net recyclable material costs after revenues	20.9	4.3	35.9
Other system costs			
Residual waste collected	137.9	28.6	32.9
Landfill	80.2	16.6	19.2
Composting green waste	13.5	2.8	
Total other costs	231.6	48.0	
Total all costs	284.9	59.0	
Total costs net of sales revenues	252.5	53.3	

Summary comments:

- The analysis indicates that revenue from the separate collection, sorting, and sales service is insufficient to cover the direct costs incurred in providing the service. The PV of total recyclable material costs of $53.3 million exceeds total revenues of PV $32.4 million by PV $20.9 million, a shortfall in revenue equivalent to 65 percent of sales revenues.
- Sales revenue of $6.7/tonne of total *waste generated* over the study period compares to costs incurred of $11.0/tonne of waste generated, a net cost to the recycling program of $4.3/*tonne of waste generated* (equivalent to $43.7/*tonne of material sold*[131]).
- Total revenues of PV $32.4 million include a transfer of PV $3.3 million to the recycling service from the residual waste collection and disposal service. This reflects costs avoided by the residual waste service from the diversion of waste to the recycling program. The transfer constitutes 14 percent of total revenue and is equivalent to $0.7/tonne of total system waste generated.
- Other system costs of PV $231.6 million consist of residual waste collection (PV $137.9 million), landfill disposal (PV $80.2 million), and green waste composting (PV $13.5 million).
- Total system costs including materials collection, sorting/ and sales are $284.9 million, equivalent to $59.0/tonne of waste generated. Total cost net of total revenue is PV $252.5 million, $53.3/tonne of waste generated.

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[131] Net revenue PV of minus $20.9 million divided by PV of total material sold of PV 0.478 million tonnes.

Annex 1: Unit costs and assumption used for preparing cost estimates

The following parameters and unit costs have been used for developing cost estimates:

Item	Value	Units
Assumptions		
Waste composition		
Food waste	44.20	%
Paper	4.55	%
Cardboard	8.45	%
Plastics	12.00	%
Textile	4.00	%
Rubber	0.30	%
Leather	0.20	%
Green waste	7.80	%
Wood	0.50	%
Glass	4.00	%
Metals	3.00	%
Inert	10.50	%
Hazardous waste	0.50	%
Waste generation rates[132]		
Urban areas	365.0	kg/capita/year
Rural areas	326.6	kg/capita/year
Lifetime of assets		
Civil works	30	Years
Civil works landfill administrative buildings and common infrastructure - related to lifetime of landfill	30	Years
Civil work individual landfill cell	5	Years
Mechanical (low wear and tear)	15	Years
Mechanical (normal wear and tear)	10	Years
Vehicles	10	Years
Containers and bins	7	Years
Other assets	5	Years
Maintenance and repair		
Civil works	1	%
Mechanical (normal wear and tear)	3	%
Mechanical (high wear and tear)	6	%
Vehicles	10	%

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[132] Assumed household waste generation rate of 0.85 kg per day per capita; 15 percent similar waste from commercial, administrative, and industrial origin in urban areas; 5 percent similar waste in rural areas.
The generation rate applies for the first year of analysis. 1 percent annual increase in generation rate assumed over the planning period.

Annex 1: Unit costs and assumption used for preparing cost estimates (cont.)

Item	Value	Units
Assumptions (cont.)		
Staff		
Staff working weeks/year	46	Weeks/year
Staff working days/week	5	Days/week
Staff working hours/day	8	Hours/day
Sick leave	5%	of total working days
Staff working days/year	219	Days/year
Other		
Discount factor	5	%
Exchange rate €1 =	1.07	$
Unit costs		
Personnel costs[133]		
Facility Manager	15,240	$/year
Deputy Facility Manager	12,192	$/year
Head of Department	9,754	$/year
Deputy Head of Department, Head of sector	8,534	$/year
Senior specialist (engineer, economist, accountant)	8,534	$/year
Foreman	7,925	$/year
Head of storage	7,315	$/year
Office assistant, administrative personnel	6,096	$/year
Skilled worker	7,315	$/year
Trained worker	5,486	$/year
Driver	7,925	$/year
Supervisor in collection	6,096	$/year
Porter	5,486	$/year
Unskilled staff	4,267	$/year
Unskilled sorters	4,267	$/year
Consumables		
Electricity	0.087	$/kWh
Freshwater	1	$/m^3
LFO	328	$/tonne
Diesel	1.3	$/l
Disposal/discharge of residues		
Leachate treatment	5.0	$/m^3
Wastewater treatment	2	$/m^3
Transport of residues to landfill	1.93	$/tonne

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[133] Presented as gross annual costs for the company, assuming 27 percent social and health security payments

Annex 1: Unit costs and assumption used for preparing cost estimates (cont.)

Item	Value	Units
Unit costs (cont.)		
Revenues		
Electricity	0.06	\$/kWh
Power from Renewable sources	0.21	\$/kWh
Paper/Cardboard	50	\$/tonne
Plastics	100	\$/tonne
Paper/Cardboard from sorting plant	30	\$/tonne
Plastics from sorting plant	60	\$/tonne
Glass	0	\$/tonne
Metal	100	\$/tonne
Compost	3	\$/tonne
RDF	0	\$/tonne
Civil works		
Excavations and earthworks	5.14	\$/m^3
Concrete Wall	295.32	\$/m^3
Access Road	385.20	\$/m
Internal roads heavy traffic	44.94	\$/m^2
Pavement Parking	17.98	\$/m^2
Fence	64.20	\$/m
Offices, workshop	449.40	\$/m^2
Industrial hall normal construction	385.20	\$/m^2
Steel construction shelters and covered areas	268	\$/m^2
Landfill sealing system	23.11	\$/m^2
Landfill surface capping	19	\$/m^2
Delivery, spreading of landfill drainage layer (gravel)	15	\$/m^3
Surface water trench	6	\$/m
Sewer for rainwater	257	\$/m
Manholes for sewer	1,926	\$/pc
Leachate drainage pipes	321	\$/m
Aerial drainage for leachate system	6	\$/m^2
Leachate shafts	38,520	\$/pc
Leachate pipe outside landfill	39	\$/m
Excavation pond, geosynthetic liner, complete	8	\$/m^3
Protective sand bedding and concrete plates for evaporation pond	13	\$/m^3
Amount measuring leachate	6,420	\$/pc
Gate	5,264	\$/pc
Water supply	64,200	\$ lumpsum

Annex 1: Unit costs and assumption used for preparing cost estimates (cont.)

Item	Value	Units
Unit costs (cont.)		
Civil works (cont.)		
Wastewater treatment plant for leachate[134]	1,284,000	$/pc
Settlement tank and separating vessel for petrol washing place	9,630	$/pc
Pump	6,420	$/pc
Tubes and pipes for pump	6,420	$ lumpsum
Gas collecting pipes	141	$/m
Gas collecting stations (underground collecting stations)	102,720	$/pc
Gas collecting station with flare 1,500 m3/h	192,600	$/pc
Gravel bedding for gas collection pipe	17	$/m^3
Gas wells	642	$/m
Pump house	6,420	$/pc
Power supply (transformer, and so on)	77,040	$ lumpsum
Cable tunnel	26	$/m
Grading and compaction of plant and paved areas	3	$/m^2
Grassing, seeding, tree plantation	14	$/m^2
Drainage of surface water	3	$/m^2
Amenity block	51,360	$/pc
Septic tank	257	$/m^3
Filling station	20,544	$/pc
Site lighting	1	$/m^2
Machinery and equipment		
Belt conveyors and accessories	4,280	$/m
Reception crane	160,500	$/pc
Magnetic separator	48,150	$/pc
Eddy current separator	205,440	$/pc
Sieve	267,500	$/pc
Trommel screen	342,400	$/pc
Air classifier	267,500	$/pc
Ballistic classifier	363,800	$/pc
Picking station	256,800	$/pc
Automated channel press with feeding lines	321,000	$/pc
Vertical baler	26,750	$/pc
Glass crushing and cleaning line	1,605,000	$/pc

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[134] Depending on leachate quantity and quality (landfill capacity/surface, rainfall, quantity of waste deposited, operating procedures) and applied wastewater treatment technology. The figure is indicative for landfill accepting 100,000 tonnes of municipal waste per year.

Annex 1: Unit costs and assumption used for preparing cost estimates (cont.)

Item	Value	Units
Unit costs (cont.)		
Machinery and equipment (cont.)		
Shredding unit 1	642,000	\$/pc
Shredding unit 2	385,200	\$/pc
Ventilation unit - mechanical part	42	$\$/m^2$
Filter for exhaust gases	102,720	\$/pc
Biofilter	10	$\$/m^2$
Stationary compactor for transfer station	267,500	\$/pc
Reception bunker for the compactor (steel construction)	25,680	\$/pc
Rail system for feeding containers to the compactor (for transfer station)	7,704	\$/pc
Civil works pumping station	3,210	\$/pc
Compost refining screen	171,200	\$/pc
Fire protection (MRF, MBT)	64,200	\$/pc
Communication facilities	12,840	\$/pc
Laboratory equipment (compost, MBT)	25,680	\$/pc
Equipment maintenance shop	6,420	\$/pc
Office equipment and furniture	1,284	\$/person
Weighbridge	23,112	\$/pc
Landfill monitoring and aftercare		
Landfill gaz infrared analyzer	12,840	\$/pc
Meteo station	9,630	\$/pc
Monitoring costs	17,719	\$/landfill cell per year
Mobile equipment		
Grader	150,000	\$/pc
Excavator	200,000	\$/pc
Water Truck	100,000	\$/pc
Landfill waste compactor (45 tonnes)	1,100,000	\$/pc
Landfill waste compactor small (30 tonnes)	750,000	\$/pc
Bulldozer	450,000	\$/pc
Bucket loader for landfill	300,000	\$/pc
Wheel Loader	100,000	\$/pc
Tipper truck for landfill	150,000	\$/pc
Roll-off tipper	109,140	\$/pc
Street Sweeper	95,658	\$/pc
Waste collection vehicle sideloader with compaction, collection vehicle with crane	215,712	\$/pc
Rear-end loading waste collection vehicle with compaction ($21\ m^3$)	160,500	\$/pc

Annex 1: Unit costs and assumption used for preparing cost estimates (cont.)

Item	Value	Units
Unit costs (cont.)		
Mobile equipment (cont.)		
Rear-end loading waste collection vehicle with compaction (16 m^3)	128,400	$/pc
Rear-end loading waste collection vehicle with compaction (8 m^3)	80,250	$/pc
Container cleaning vehicle	128,400	$/pc
Forklift	32,100	$/pc
Car	19,260	$/pc
Pickup	25,680	$/pc
Compost turning machine, tractor PTO	53,500	$/pc
Windrow turner 1	695,500	$/pc
Windrow turner 2	481,500	$/pc
Windrow turner 3	321,000	$/pc
Windrow turner 4	214,000	$/pc
Shredder 1	535,000	$/pc
Shredder 2	374,500	$/pc
Shredder 3	192,600	$/pc
Small chipper	32,100	$/pc
Compost refining screen 1	256,800	$/pc
Compost refining screen 2	149,800	$/pc
Small compost screen	10,700	$/pc
Tractor	96,300	$/pc
Tractor trailer	19,260	$/pc
Mobile water tank with pump	6,420	$/pc
Semipermeable membrane for compost windrow cover	18	$/$m^2$
Tires	2,568	$ per set of tires
Containers		
Containers 1,100 liter metal	642	$/container
Containers 1,100 liter plastic	364	$/container
Bin 120/240 liter	64	$/container
Container slab[135]	—	$/container
Roll-off container	4,622	$/container
Igloo container separate collection fiber glass 1.5 m^3	856	$/container
Metal stationary container 2.2 m^3	910	$/container

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[135] No construction costs for container slabs included in cost estimates.

Annex 2: Discounted cash flow analysis (DCF)

Preparing a project in the municipal waste sector entails identifying and comparing alternative ways of achieving the desired project objectives. As project alternatives have different cost profiles (involving different cash outlays on capital and operating expenditures over the planning period), a tool is needed to compare these different cash flows between the options being examined. This is done using DCF analysis, a technique that translates a future uneven cash flow into a single PV. DCF analysis is used in various aspects of project evaluation, including comparing options for meeting policy objectives, estimating the unit costs of waste systems and system components, and estimating the annual revenue required for full cost recovery over time. To use DCF analysis effectively, it is necessary to have a good understanding of the underlying cash flows, the time value of money, the time frame of the analysis and the appropriate discount rate to be used.

Cash flows consist of cash expenditures (cash outflows) and cash incomes (cash inflows). In the cost analysis, we are mainly dealing with cash outflows (expenditures). Cash flows should be incremental to the current system, arising solely on account of the project. Existing costs (such as office overheads) should not be included: only incremental changes to those costs should be included (for example, an increase in office overheads). Costs that would be incurred irrespective of whether the project goes ahead or not should not be included, nor should costs already incurred.

Only the direct capital investment and operating expenditures incurred over the planning period should be used in the DCF analysis. These are the actual cash outlays incurred in purchasing the equipment, materials, and labor needed to construct, operate, and maintain the service. They do not include expenditures associated with financing the project (for example, debt service charges) or accounting provisions (such as depreciation or provisions for amortizing liabilities incurred after plant closure).

Capital expenditures include land purchase, site development, buildings, infrastructure, plant and equipment, licenses, patents, and other preproduction expenses and permits. Incremental operating expenditures include labor costs, vehicle fuel, other energy requirements, raw materials, chemicals, utilities, repairs and maintenance, administrative costs, and insurance.

Only future costs should be included in the financial cash flow. Costs that have already been incurred or which are committed regardless of the investment decision made are not relevant and should be excluded. Reinvestment costs (expenditures to replace assets with economic lives shorter than the planning period) should be included in the year in which they are incurred.

The expected value remaining in an asset at the end of the planning period is called its residual value and should be included as an income in the project cash flow. It is usually regarded as the non-depreciated value of the initial or replaced assets and is entered in the final year of the planning period. The residual value is then discounted to determine its PV in today's terms.

Future cash inflows and outflows should be presented in constant values. That is, they should reflect the prices prevailing in the year in which the analysis is being undertaken. Adjustments made in future years should only reflect projected changes in the real prices of goods and services (for example, in wage rates or the price of energy); price changes brought about solely as a result of general price inflation should be ignored. VAT should be excluded from DCF analysis. It is well known for those involved in project development to underestimate costs and overestimate revenues. In practice, costs tend to rise and revenues to fall, and care should be taken to ensure that costs are based on realistic assessments and that bias—particularly optimism bias—is avoided.

The 'time value of money' is the concept that money held today is worth more than the same amount of money received in the future: future cash flows are discounted to estimate their equivalent values today (that is, their PV). PV is the value of a cash flow discounted to a common reference point in time (also known as 'today's' value).

The discount rate reflects the 'opportunity cost of capital', a measure of the opportunity foregone by using scarce capital resources in the project rather than in an alternative use. It reflects both the value of the risk-free investment opportunities foregone by the decision to invest in the project (depositing the funds in a deposit account, for example) and the relative risk characteristics of the project. The discount rate to be used for public projects is commonly specified by the national authorities. Rates of 3.5–5.0 percent in real terms are typical, although they can be significantly higher in countries with tightly constrained capital resources.

Cost-Effectiveness Analysis (CEA) (also known as Least-Cost Analysis)[136] is a technique which uses PV alone to compare the financial costs of projects that have *identical* outcomes (for example, the quantity of waste collected or treated) but which have different investment and operating cost profiles (possibly higher or lower investment costs and higher or lower operating costs).[137] For example, CEA can be used to compare two regional landfill location options that achieve the same environmental goals but cannot be used to compare an incineration plant with a composting plant (for which the environmental outcomes are different). AIC analysis—a variant of CEA—can overcome this restriction.

Cost-effectiveness is measured as the PV of the relevant project cost flow. Options are compared and the one with the lowest PV is referred to as the least-cost option. The least-cost approach is closely related to the more powerful concept of AIC analysis and has the important advantage of being able to calculate and compare systems according to their unit costs (see below).

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[136] An example of the cost-effectiveness approach is its use in defining the least-cost way of meeting specified standards or legislation. Legislative compliance usually has an element of prescription to it, where regulations and standards (or where an environmental goal has been set by national policy or international agreement) must be complied with but where it is not necessary to show that the benefits of doing so outweigh the costs.

[137] Least-cost analysis gives us the least-cost method of achieving a specific objective but says nothing about whether a project is financially viable or not (or whether it adds economic value to society).

Annex 3: AIC analysis (unit cost analysis)

Overview

The PV of a future cash flow is a useful measure for comparing the cost-effectiveness of alternative strategies that provide identical levels of service. It cannot, however, be used for alternative strategies that provide different levels of service. To make up for this, an extension of CEA known as AIC analysis is used to compare alternative strategies that provide different levels of service. It is a principal tool used in the evaluation of alternative waste management strategies. It takes account of both the PV of the cashflow and the PV of the waste (or other material) flow. The AIC—the average $/tonne calculated over the planning period—is the single factor differentiating AIC analysis from CEA.

AIC analysis is a simple concept and powerful tool for comparing projects according to their unit costs (for example, $/tonne of waste treated). It enables comparisons to be made between the costs of fundamentally different projects. For example, between the unit costs of a waste incineration plant with those of a composting plant or between the waste collection and landfill components of a waste management system. It enables the economies of scale of increasingly higher capacities of processing plant to be defined. It provides a sound basis for assessing the affordability of a proposed strategy, and for defining the average tariff needed to achieve full cost recovery from users.

The strength of the AIC analysis is that it enables an uneven cost flow (a) to be reduced to a single PV which can (b) be converted into an equivalent smooth revenue flow which covers the uneven cost flow in full. AIC is the uniform unit cost (cost/tonne) which when applied to the annual waste flow will generate a revenue flow having a PV equal to that of the cost flow. That is, the unit cost is an estimate of the uniform tariff which will recover costs in full when applied to the relevant waste stream.

It enables the investment and operational costs incurred over the planning period to be allocated relative to the quantity of waste managed each year. It means that the revenue requirement in a specific year relates directly to the quantity of waste managed in that year. That is, it enables costs to be matched closely with demand. This differs from the traditional approach, whereby investment costs are allocated uniformly over time via the depreciation process without accounting for the size of the annual waste management task. This difference has important implications for unit cost and tariff setting.

It can help waste practitioners to

- Understand the financial structure, dynamics and costs of their waste systems;
- Evaluate system options and the cost consequences of introducing new system components;
- Undertake longer-term systems planning, budgeting, and tariff analysis.

The approach can readily be used without complex modelling to provide rapid and reliable information on unit costs, revenue requirements, and tariffs with only limited investment and operating cost data. It is one of the two approaches used for calculating the annual revenue requirement and tariffs, the other being the TA approach (outlined in Section 2.4.4).

Calculating AIC

AIC analysis relies on the elements of DCF analysis: namely the planning period, the discount rate, the residual value of capital assets, and PV. The AIC is calculated from the PV of the resource costs (investment and operational) flows[138] and the PV

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[138] Note that costs are resource costs, being the actual investment and O&M cash outlays. Depreciation is excluded, as including it would be double counting investment costs.

of waste (material) quantity flows.[139] AIC has a fixed value which when applied to a relevant physical flow generates a revenue flow having a PV equal to that of the cost flow. AIC analysis enables an uneven cost flow to be transformed into an equivalent smooth quantity-based revenue flow that covers the total cost flow in full. The AIC is an indicative estimate of the full cost recovery tariff per tonne of waste collected over the planning period.

AIC and the equivalent revenue stream are calculated as follows:

- Calculate the net cost cash flow for each year of the planning period[140]
  - Net Cash Flow = Investment Costs + Operating Costs – Residual Value
- Calculate the PV of the net cash flow
  - PV (Net Cash Flow)
- Tabulate waste quantities to be collected[141] for each year of the planning period (the waste flow)
- Calculate the PV of the waste flow[142]
  - PV (Waste Flow)
- Calculate the AIC/tonne of waste collected by dividing the PV of the net cash flow by the PV of waste flow
  - AIC = PV (Net Cash Flow) / PV (Waste Flow)
- Calculate the equivalent annual revenue requirement as the product of the annual waste flow and the (constant value) AIC
- Calculate the PV of the annual revenue requirement cash flow.
  - PV (Annual Revenue Requirement Cash Flow)
- The PV of the annual revenue requirement is identical to the PV of the net cash flow.
  - PV (Annual Revenue Requirement Flow) = PV (Net Cash Flow)

Table A3.1: Example AIC calculation and equivalent full cost recovery revenue flow

Discount rate = 5%	**PV**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Physical flow (tonnes)	553	40	50	80	100	100	100	100	100
Net cash flow (₮)	4,648	2,000	750	400	400	400	400	400	400
AIC (₮/tonne)	8.4								
Equivalent revenue flow (₮)	4,648	336	420	673	841	841	841	841	841

AIC = PV (Net Cash Flow) / PV (Physical Flow)

AIC = ₮ 4,648 / 553 tonnes = 8.4 ₮/tonne

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[139] Justification for discounting a physical flow such as waste to be provided.

[140] The term 'net cost cash flow' is used as investment costs are net of their residual value at the end of the analysis period.

[141] The waste flow can be related to any system component, such as tonnes of recyclable material or tonnes of waste disposed of to landfill.

[142] Briefly explain the mathematics behind discounting a physical flow such as waste.

The calculations are illustrated in the following example.

Simple operational examples of AIC analysis

A project entails a planning period of six years; a single investment of $10,000; an investment life of eight years; waste flow at full capacity utilization of 120 tonne/year; fixed operating costs of $1,500/year; variable operating costs of $8/tonne of material throughput. Two scenarios are considered:

- Scenario 1: Full plant capacity utilization from year 1
- Scenario 2: Ramp up to full plant capacity over four years.

The following tables set out the analysis for each scenario. The examples are also applied in Annex 4 when considering the TA approach. The outcomes of the two approaches are compared in Annex 5.

Table A3.2: Simple AIC example - fixed annual waste flow

Units: $; discount rate: 5%	PV	1	2	3	4	5	6
Asset life (years)	8						
Waste flow	640	120	120	120	120	120	120
Investment expenditure	10,000	10,000	0	0	0	0	0
Residual value	–1,959	0	0	0	0	0	2,500
Total operating costs	13,111	2,460	2,460	2,460	2,460	2,460	2,460
Fixed operating cost	7,994	1,500	1,500	1,500	1,500	1,500	1,500
Variable operating cost	5,116	960	960	960	960	960	960
Net cost cash flow	21,152	12,460	2,460	2,460	2,460	2,460	-40
AIC	33						
Equivalent revenue stream	21,152	3,969	3,969	3,969	3,969	3,969	3,969

Points to note:

- A single asset is created with a life of eight years and an initial investment of $10,000. At the end of the six-year planning period, the residual value of the asset is $2,500 in year 6 and a PV of $1,959. The value remaining in the project of $1,959 is treated as a revenue flow.
- The annual waste (material) flow is constant over the period, as are annual operating costs.
- The net cash flow is uneven (consisting of investment costs, operating costs, and residual value) and has a PV of $21,152.
- The AIC is calculated as $33/tonne of waste management over the planning period, dividing the PV of the net cash flow by the PV of the waste flow.
- The equivalent revenue stream is calculated as the AIC multiplied by the waste flow in each year. Note that it has a PV of $21,152 (the same as the net cash flow).

Table A3.3 reflects the same analysis but with the input material flow ramped up over the first three years after which it is constant.

Table A3.3: Simple AIC example - variable annual waste flow

Units: $; discount rate: 5%	PV	1	2	3	4	5	6
Asset life (years)	8						
Waste flow	503	40	80	100	120	120	120
Investment expenditure	10,000	10,000	0	0	0	0	0
Residual value	(1,959)	0	0	0	0	0	(2,500)
Total operating costs	12,021	1,820	2,140	2,300	2,460	2,460	2,460
Fixed operating cost	7,994	1,500	1,500	1,500	1,500	1,500	1,500
Variable operating cost	4,026	320	640	800	960	960	960
Net cost cash flow	20,062	11,820	2,140	2,300	2,460	2,460	(40)
AIC	40						
Equivalent revenue stream	20,062	1,594	3,189	3,986	4,783	4,783	4,783

Points to note:

- Material flow input starts relatively low and is gradually increased until it reaches full capacity input in year 4.
- Investment expenditures are the same, as are residual value and fixed operating costs. Variable operating costs vary according to the material inflow profile.
- The PV of the net cost cash flow is lower, owing to the lower material throughput.
- An AIC of $40/tonne is higher, also due to the lower material throughput.
- The equivalent annual revenue requirement is calculated as the product of the AIC and material flow and is again identical to the PV of the net cost cash flow. Note that the revenue stream reflects annual demand (increasing material flow).

Note that dividing the PVs of the fixed and variable components of O&M costs by the PV of the waste flow gives AICs for each of the two cash flows. Together they equal the PV of the total operating cost flow. The AIC for variable O&M costs is 4,026 / 503 = $8/tonne (as expected) and for fixed O&M costs it is $16/tonne. The AIC for total investment expenditures is $10,000/$503 = $20/tonne, and for residual value it is minus $3.9/tonne.

Note also that the AICs of $33/tonne and $40/tonne of material managed for the two scenarios are constant across the planning period.[143] For Table A3.1, it is the same each year, consistent with a constant annual demand over the planning period. The two revenue flows are illustrated in Figure A3.1.

The key point is that the revenue requirement increases with increasing material flows (that is, it matches demand). These are compared with the outcomes derived using the traditional approach in Chapter 7.

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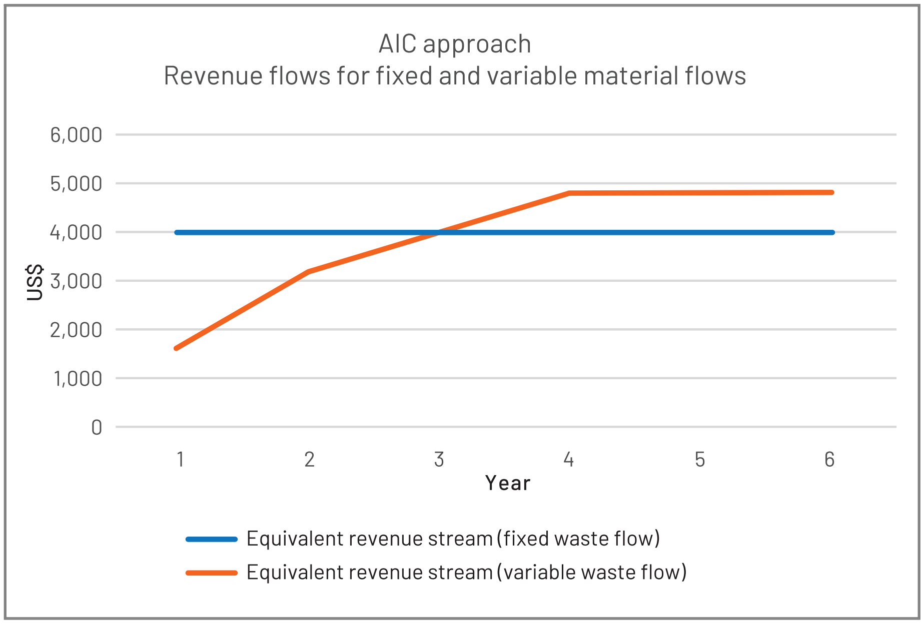
[143] Note that the financial numbers are in the real constant values of a specific year (year 1) and are not adjusted for inflation.

Figure A3.1: Revenue flows for fixed and variable material flows (AIC approach)



Annex 4: A traditional accounting approach

The core difference between the TA and the AIC approaches to defining annual revenue requirements and equivalent tariffs lies in their treatment of investment parameters and time. The TA approach calculates the annual revenue requirement and tariff directly from accounts-based data on operating costs, asset depreciation, and ROI:[144] Calculations in one year are independent from those in following years. They are not linked by time or service demand.

Outline of the TA approach

The accounting approach calculates the annual revenue requirement as O&M costs plus depreciation (the return *of* investment) plus the ROI (the average of the starting and closing values of an asset in any particular year). These items are typically calculated each year for accounting purposes. Indicative tariffs are calculated for each year by dividing the annual revenue requirement by the total waste collected in that year ($/tonne), the size of the serviced population ($/person), or the number of households served ($/household).

Allocating investment costs via the depreciation provision means they are allocated purely according to time and not the size of demand for services in each year (that is, the amount of waste collected or the size of population served). In a situation of projected rising population or rising per capita waste generation (or both), the approach results in higher unit costs per tonne or per person in earlier years than in later years. Not only does this conflict with objectives such as the user- and polluter-pays principles, it also defeats the aim to increase tariffs progressively over time as they become increasingly more affordable through real income growth.

Calculating the full cost recovery tariff and annual revenue requirement using the TA approach requires three sets of information:

- Annual O&M expenditures over the period of the analysis (usually the projected life of the landfill or other assets having the longest economic life).
- Annual depreciation (the return *of* capital): calculated by dividing the initial value of each asset by its economic life). Depreciation is essentially fixed over the expected life of each asset.
- The annual rate of ROI: calculated as the product of the *average* annual value of the *depreciated* assets in a specific year and the rate of return.

The sum of these parameters gives the annual revenue requirement for full cost recovery.

The average annual value of the depreciated asset base is taken to be the average of the annual opening and closing values of the assets. The required ROI is assumed to be the same as the discount rate employed in the AIC approach.

In the TA approach the annual revenue requirement to achieve full cost recovery is calculated ***in each year*** of the analysis period. It is converted to an annual cost per tonne of waste by dividing it by the projected amount of waste managed in the relevant year. This can also be related directly to users in terms, for example, of the annual cost per person, per household or per unit floor area. This indicative financial tariff can then be adjusted for any additional cost items, such as VAT.

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[144] Note that the three parameters (annual operating costs, depreciation, and ROI) are the accounting equivalents of those used of annual operating costs, investment cash expenditures, residual value, and discount rate to define the net cash flow calculation in the AIC approach.

Examples of the TA Approach

The following is an example of the calculations made using the TA approach.

Table A4.1: Simple TA example - fixed annual waste flow

Units: $; discount rate: 5%	PV	1	2	3	4	5	6
Asset life (years)	8						
Waste flow (tonne)	640	120	120	120	120	120	120
Investment expenditure	10,000	10,000	0	0	0	0	0
Depreciation	6,662	1,250	1,250	1,250	1,250	1,250	1,250
Starting asset value		10,000	8,750	7,500	6,250	5,000	3,750
Ending asset value		8,750	7,500	6,250	5,000	3,750	2,500
Average asset value		9,375	8,125	6,875	5,625	4,375	3,125
ROI	1,713	469	406	344	281	219	156
Total operating costs	13,111	2,460	2,460	2,460	2,460	2,460	2,460
Fixed operating cost	7,994	1,500	1,500	1,500	1,500	1,500	1,500
Variable operating cost	5,116	960	960	960	960	960	960
Revenue requirement	21,485	4,179	4,116	4,054	3,991	3,929	3,866
Annual cost/tonne		35	34	34	33	33	32

Points to note:

- Waste (material) flows, investment expenditure, and asset life are as per Table A4.1 and Table A4.2, as are fixed and variable operating costs.
- The revenue requirement is calculated annually as depreciation plus ROI plus operating costs.
- The ROI is calculated as the rate of return required multiplied by the annual average asset value.
- The annual revenue requirement falls over the planning period. This results from falling average asset values and the resulting lower annual ROI (prior to asset replacement).
- The unit cost per tonne of waste managed is calculated by dividing the annual revenue requirement by the annual quantity of material managed. The unit cost per tonne falls in tandem with the fall in the annual revenue requirement.
- Note also that the annual cost per capita (or per household) is calculated as the annual revenue requirement divided by number of residents served (taken to be constant in the above).

Table A4.2: Simple TA example - variable annual waste flow

Units: $; discount rate: 5%	PV	1	2	3	4	5	6
Asset life (years)	8						
Waste flow (tonnes)	503	40	80	100	120	120	120
Investment expenditure	10,000	10,000	0	0	0	0	0
Depreciation	6,662	1,250	1,250	1,250	1,250	1,250	1,250
Starting asset value		10,000	8,750	7,500	6,250	5,000	3,750
Ending asset value		8,750	7,500	6,250	5,000	3,750	2,500
Average asset value		9,375	8,125	6,875	5,625	4,375	3,125
ROI	1,713	469	406	344	281	219	156
Total operating costs	12,021	1,820	2,140	2,300	2,460	2,460	2,460
Fixed operating cost	7,994	1,500	1,500	1,500	1,500	1,500	1,500
Variable operating cost	4,026	320	640	800	960	960	960
Revenue requirement	20,395	3,539	3,796	3,894	3,991	3,929	3,866
Annual cost/tonne		88	47	39	33	33	32

In this scenario, material throughput is ramped up progressively each year as outlined in Table A4.2.

Points to note:

- Investment expenditures, depreciation, average asset values, and ROI are unchanged from Table A4 - 1.
- Differences in input data between the two tables are (i) the material flows and (ii) the variable operating costs (which are linked to material quantity).
- The PV of the annual revenue requirements of $20,395 is $1,090 lower than the equivalent PV figure of $21,485 calculated in Table A4.1. This is entirely due to lower variable operating costs.
- Note that the annual revenue requirement first increases as material throughput is ramped up to full capacity (years 1 to 3) but then falls over years 4 to 6 when full capacity has been achieved (as also demonstrated in Table A4.1).
- The major difference arises in the calculation of the annual costs per tonne in years 1, 2, and 3. The figure of $88 calculated for year 1 results from the accounting costs on which it is based ($3,539) being unrelated to the quantity of material being managed (40 tonnes as compared to a full capacity throughput of 120 tonnes). This is a major failing of the approach: costs are not allocated according to demand.[145] These outcomes are illustrated in the Figure A4.1 and A4.2.

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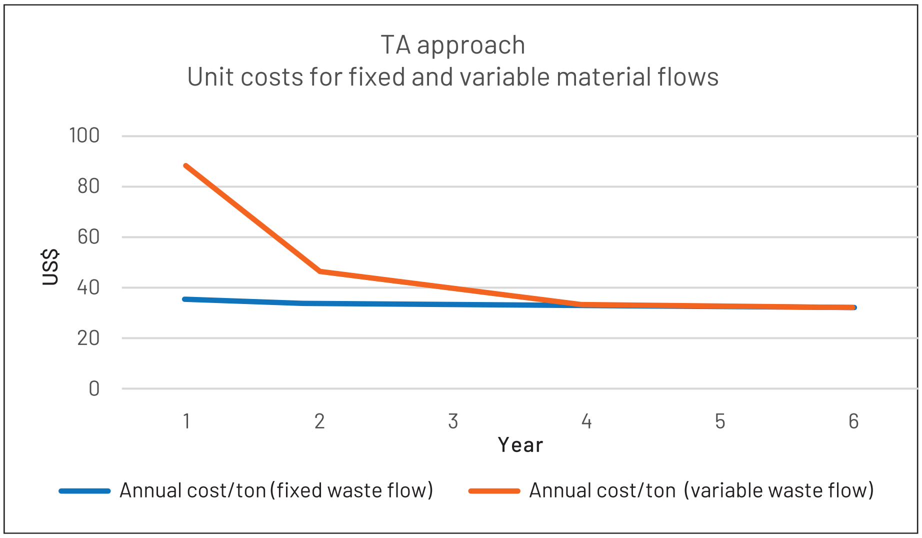
[145] The same issue arises if the annual cost per capita (or household) is calculated.

Figure A4.1: Unit costs for fixed and variable material flows (TA approach)

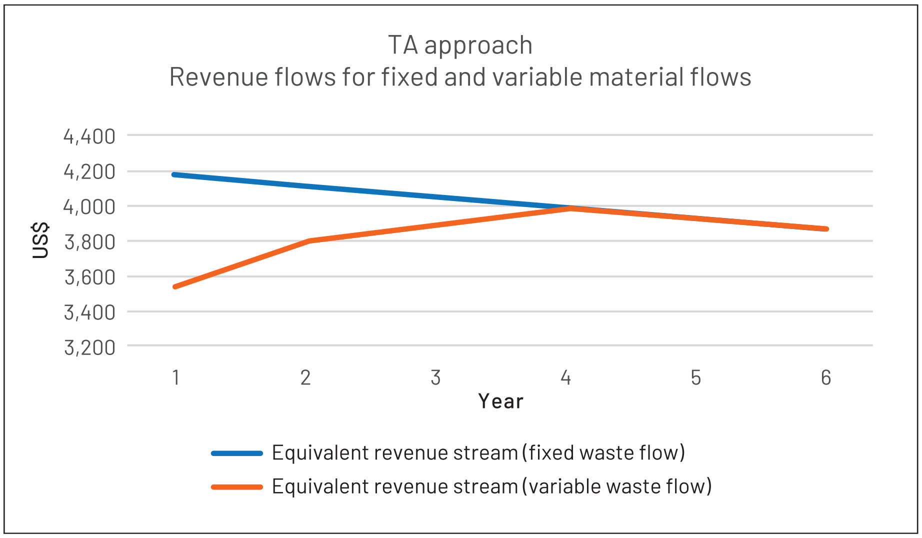


The outlying figure of $88 per tonne distorts the scale of the diagram above insofar as the progressively declining annual cost per tonne of the fixed waste flow scenario (in blue) is not easily seen. This applies equally to the final three years of the variable waste flow scenario (in orange).

The following chart illustrates

- The progressively declining revenue requirement in the fixed waste flow example (Scenario 1);
- The progressively rising revenue requirement of the variable waste flow example (Scenario 2) over the first three years as material input is being ramped up, after which it declines (as per Scenario 1).

Figure A4.2: Revenue flows for fixed and variable material flows (TA approach)

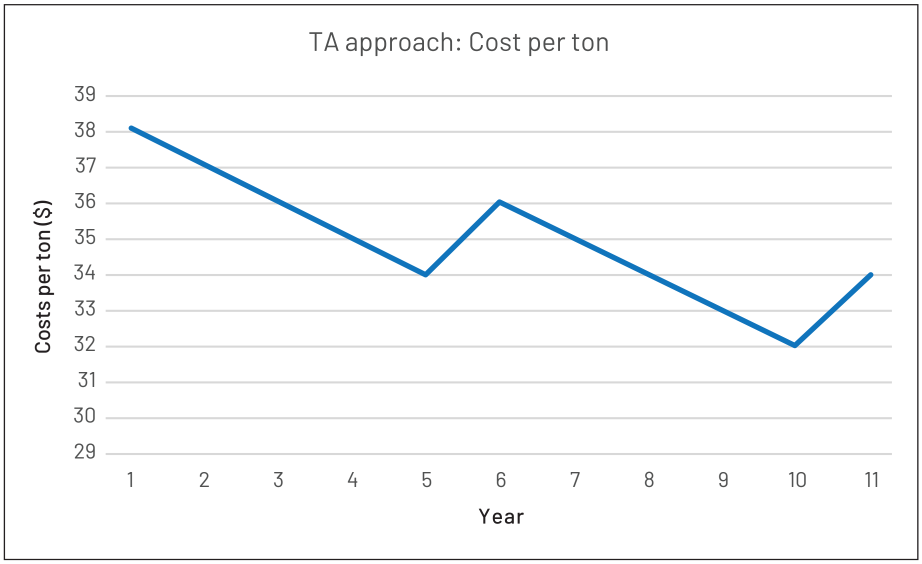


Problems with the TA Approach

Problems associated with the TA approach:

- The approach is based on annual capital accounting and operating costs and is unrelated to service demand (waste quantity collected per year).
- It is undertaken on an annual basis and relates only to time (depreciation and ROI are calculated annually) and not to waste quantity or population size.
- It implies that the accounting costs incurred in one year (such as depreciation) should be recovered in that year: this does not necessarily apply.
- It is erratic, leading to volatility in tariffs and revenue flows (see Figure A4.3).
- It provides little scope for flexibility in tariff setting.
- It does not help with longer-term strategic and financial planning.

Figure A4.3: Cost per tonne (TA approach)



The chart shows a typical profile of unit costs per tonne when the TA approach is used to calculate it.

Annex 5: Comparing the AIC and TA approaches

This annex compares the unit cost, revenue and tariff outcomes using the AIC and accounting approaches. The examples are based on identical waste flows, investment and operating costs, and planning time frames. The following outcomes are identical in all situations:

- Arithmetic average cost per tonne calculated over the planning period
- Arithmetic average tariff per capita calculated over the planning period
- The PV of the resultant revenue streams.

The difference between the approaches is the way costs are allocated and the effect of this on tariffs over the planning period.

Table A5.1: Comparison of AIC and TA approaches: Fixed annual waste flow

Units: $; discount rate: 5%	PV	1	2	3	4	5	6
Asset life (years)	8						
Waste flow (tonnes)	640	120	120	120	120	120	120
AIC approach							
Investment expenditure	10,000	10,000	0	0	0	0	0
Residual value	–1,959	0	0	0	0	0	–2,500
Total operating costs	13,111	2,460	2,460	2,460	2,460	2,460	2,460
Net cost cash flow	21,152	12,460	2,460	2,460	2,460	2,460	–40
AIC/tonne	33	33	33	33	33	33	33
Equivalent revenue stream	21,152	3,969	3,969	3,969	3,969	3,969	3,969
TA approach							
Depreciation	6,662	1,250	1,250	1,250	1,250	1,250	1,250
ROI	1,713	469	406	344	281	219	156
Total operating costs	13,111	2,460	2,460	2,460	2,460	2,460	2,460
Revenue requirement	21,485	4,179	4,116	4,054	3,991	3,929	3,866
Annual cost/tonne		35	34	34	33	33	32

The example relates to a system of fixed annual waste flows. The AIC approach first calculates the net cost cash flow. From this AIC/tonne is calculated by dividing the PV of the net cost cash flow by the PV of the Waste Flow. The AIC is then used to calculate the annual revenue requirement, a revenue flow having a PV which is identical to that of the net cost cash flow and covers the net costs in full. The TA approach separately calculates the annual revenue requirement for each year and estimates from it the average cost per tonne of waste managed each year. Unit costs are calculated by dividing the annual revenue requirement by the annual quantity of waste managed. Although not identical, the TA approach leads to a PV of the annual revenue requirement ($21,485) which comes close to that of the AIC approach ($21,152). Applied properly, the approaches can realistically be considered identical in this respect.

They differ with respect to the allocation of the revenue requirement over the planning period and the value of the AIC/Annual cost per tonne. First, the AIC/tonne is a unique number applicable to each tonne of waste managed across the planning period. It is calculated as $33/tonne of waste. In contrast, with the TA approach, the unit cost per tonne of waste varies across the planning period, falling from a high figure of $35/tonne in year 1 to a low figure of $32 in year 6. Similarly, the annual revenue requirement under the AIC approach of $3,969 is the same across the planning period; this is realistic, as the number is calculated from two constants, the AIC and the quantity of waste managed. The figure of $4,179 calculated for year 1 under the TA approach is the highest of the annual figures, falling to $3,866 in year 6. These are perverse outcomes of the TA approach.

Table A5.2: Comparison of AIC and TA approaches - Variable annual waste flow

Units: $; discount rate: 5%	PV	1	2	3	4	5	6
Waste flow (tonnes)	503	40	80	100	120	120	120

AIC approach							
Investment expenditure	10,000	10,000	0	0	0	0	0
Residual value	–1,959	0	0	0	0	0	–2,500
Total operating costs	12,021	1,820	2,140	2,300	2,460	2,460	2,460
Net cost cash flow	20,062	11,820	2,140	2,300	2,460	2,460	(40)
AIC	40	40	40	40	40	40	40
Equivalent revenue stream	20,062	1,594	3,189	3,986	4,783	4,783	4,783

TA approach							
Waste flow (tonnes)	503	40	80	100	120	120	120
Depreciation	6,662	1,250	1,250	1,250	1,250	1,250	1,250
ROI	1,713	469	406	344	281	219	156
Total operating costs	12,021	1,820	2,140	2,300	2,460	2,460	2,460
Revenue requirement	20,395	3,539	3,796	3,894	3,991	3,929	3,866
Annual cost/tonne		88	47	39	33	33	32

Table A5.2 relates to a system of variable annual material flows. Here, an AIC of $40 is calculated with the AIC approach. It is larger than that of $33 for the fixed waste flow, a difference resulting from a significant reduction in total waste managed but only a relatively small reduction in total costs owing to the high fixed cost element of total costs. The revenue stream is a relatively low figure ($1,594) as it is the product of a fixed AIC and a low volume of waste managed.

Regarding the TA approach, the annual revenue requirement of $3,539 in year 1 initially grows until full capacity is reached in year 4, after which it starts to fall. Note that the revenue requirement estimated for year 1 of $3,539 is more than double that of $1,594 calculated with the AIC approach. Again, a perverse outcome of the TA approach is the high annual costs per tonne of $88, $47, and $39 in years 1 to 3. This is due to a low volume of material being treated while the accounting costs of depreciation and ROI remain unchanged with only a relatively small fall in variable operating costs. That is, a large cost must be covered by a small quantity of material being managed.

Summary: Why the AIC approach is important

- Fairly allocates costs against service use
- Takes account of projected future population and waste generation dynamics in calculating tariffs today
- Recovers costs in full over the planning period
- Generates a steady and predictable revenue stream
- Starts from a lower tariff base than accounting-based schemes
- Generates an identical revenue stream in PV terms when compared to the accounting-based approach
- It is versatile and can be very easy to apply.

Annex 6: Affordability and financial sustainability

Two constraints should be considered when assessing household waste tariffs: their affordability for users and their ability to sustain the services financially over time. System planners face two pressures: to keep tariffs lower for affordability and to keep them higher for financial sustainability. Usually, two separate tariff assessments are made: one to define an affordable tariff profile (and its associated revenue stream) and another to define the tariffs needed to satisfy the minimum revenue requirement for financial sustainability. The affordability assessment is undertaken independently from system costs whereas the financial sustainability assessment depends on costs.

Affordable tariff policy tends to pull tariffs down and financial sustainability tariff policy tends to push them up. The tensions inherent in these goals feed back into system financing and, ultimately, into how the waste management system itself is defined. A funding gap between the two shows how grant funding (or other additional funding supports, such as municipal transfers) may be needed to fill the gap between the affordable and full cost recovery tariff paths. Alternatively, it might be necessary to redefine the scope, scale, and costs of the project.

The affordability assessment draws on the socioeconomic parameters of the community being served and is unrelated to the proposed strategy and its costs. Assumptions underpinning the assessment are codified at the end of the section as a set of decision rules to be used when calculating the affordable tariff.

Decision Rules

The aim is to define a tariff and financing structure that enables both tariff constraints to be met, an aim which decision rules can be set to achieve:

- Decision rules help define the input parameters needed to establish household waste tariffs that are socially affordable and acceptable. They help define an affordable revenue stream.
- Decision rules help define the minimum revenue needed each year to achieve system financial sustainability. They help define the tariffs needed to satisfy this constraint.

Example decision rules for assessing the affordability of municipal waste services:

- Define the average household (or per capita) income and projections to be used in the analysis;
- Define an affordability ratio for municipal waste tariffs relative to average household income;
- Define an appropriate starting tariff to initiate the future tariff evolution process;
- Define a realistic period over which the affordable tariff is to be achieved; and/or
- Define the maximum permissible annual real rate of increase in tariffs;
- Define the correct treatment of VAT on waste management tariffs;
- Ensure that tariffs do not exceed the affordability ratio (which is expected to remain constant as average incomes rise);
- Ensure that tariffs do not exceed the full cost recovery tariff.

Example decision rules for assessing the financial sustainability of household waste services:

- Grants funds to be used (if available) to achieve the financial sustainability objectives while keeping tariffs affordable to users.

- Grants should ideally be used only once to part fund the initial investment requirements.
- Asset replacement to be funded from commercial and municipal sources (retained municipal earnings, loans or private sector contributions).
- Tariffs to cover—at a minimum—O&M costs (excluding depreciation) in full from the start of operations.
- Tariffs to cover 100 percent of depreciation on replaced assets.
- Cumulative net cash flow to be positive in all years.

Affordability, financial sustainability, and grant fund availability determine the scope, scale, and timing of implementing a realistic and achievable waste management strategy. Careful consideration of these factors can allow realistic targets to be set for achieving specific municipal waste management goals. Responsible authorities should define (a) the bounds of a socially affordable and politically acceptable tariff and its structure; (b) how the minimum annual revenue requirement is to be calculated (thereby defining the full cost recovery tariff); and (c) the sources and availability of grant funds (including budgeted municipal transfers). In the absence of grant funds, the scope, scale, and costs of the strategy will need to be scaled down to satisfy the affordability and financial sustainability criteria.

Glossary of cost categories, types and tools used in municipal solid waste management

AIC analysis

AIC analysis is an extension of DCF analysis that is widely used in the preparation of resource-based projects in sectors such as water, forestry, energy, mining, and waste management. It enables an uneven cost flow to be converted into an equivalent smooth revenue flow which covers the uneven cost flow in full. It involves the following steps:

- Calculate the PV of the cost flow.
- Divide the PV of the cost flow by the PV of the waste material flow to generate an AIC (a unit cost/tonne).
- Multiply the annual waste flow by the AIC to generate an even revenue flow having a PV equal to that of the cost flow.

The AIC is an indicator of the uniform tariff which would cover costs in full when applied to the relevant waste stream over time (before taxes, such as VAT). It enables the investment and operational costs incurred over the assessment period to be allocated relative to the quantity of waste managed in each year. That is, the cost recovery revenue requirement in a specific year relates directly to the quantity of waste managed in that year.

Debt Service

If the waste management services are financed partly by debt, then provision must be made to service the loan from the annual revenue requirement. Debt service includes two (main) cost components: repayment (return) of the principal amount annually over a defined payment period and interest payments made on the amount of loan outstanding. The close similarity between the two loan service components and the terms depreciation (return of investment) and ROI should be noted. The current report does not cover system financing.

Depreciation

Depreciation—the return *of* investment—is an approach to allocating capital outlays over the projected life of an acquired capital asset. It is a measure of the annual value of the asset used up in system operations for each year of its expected life. Depreciation is commonly calculated using the simple 'straight-line' method of dividing the initial capital outlay by the useful life of the asset, resulting in an equal provision for depreciation each year. The approach is ideal if the asset is expected to be operated broadly at its design capacity over its expected life but less so if, for example, capacity utilization is expected to vary significantly from year to year or if full capacity utilization is not expected to be reached until later in the asset's life. Under these circumstances, the AIC approach of allocating asset costs against projected material throughput (such as progressively ramping up the capacity utilization of an MRF plant) should be considered.[146]

Depreciation is not a cash flow item as it does not involve an expenditure of funds. It is an accounting procedure that enables the value of an asset to be allocated over its expected life for tax or accounts reporting purposes and which can be recovered from users through the tariff structure. It should not be included in DCF analysis (as it is not a cash flow item). It is, however, included in the calculation of the annual revenue requirement when using the TA approach to unit cost and tariff setting.

Estimates of depreciation are needed to calculate residual value in DCF and AIC calculations and are a key parameter in the TA approach to annual tariff calculations.

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[146] The AIC approach is described in this document.

Direct costs

Municipal waste management costs can be divided into their direct and indirect costs components. The direct component relates to the costs incurred in physically providing the services: the costs of acquiring the capital equipment on which the services depend (such as refuse collection vehicles or a materials recovery plant) and the costs incurred in operating that equipment (for example, labor, fuel, maintenance). Direct costs are costs that are clearly and exclusively associated with the physical activity of SWM. Direct costs are typically a significantly larger component of total costs than the indirect component. The direct cost component can be divided into a fixed cost component and a variable cost component. Variable costs vary according to the quantity of material produced. At 65–80 percent, the fixed cost component is typically higher than the variable cost component.

Discounted cash flow (DCF) analysis

DCF analysis is a tool used by financial analysts and project managers to evaluate the viability of a commercial venture or asset projected to create a financial flow over time. More broadly, it is a method to calculate the PV (today) of a projected future cash flow over time. It is based on the principle of the time value of money, whereby the PV of an asset is equal to the sum of all projected future cash inflows or outflows discounted to the present by the time value of money or discount rate.

Fixed costs

Fixed costs are costs that are independent of volume and are not linked to the amount of waste collected or treated. They are constant whatever the level of operations (within the capacity constraints of the installed capacity). Examples are rent and lease costs, depreciation, amortization, salaries, utility bills, fuel costs, insurance, and loan repayments. These are recurring costs and are hence based on time rather than on the quantity of waste collected or treated (for example, interest, labor and insurance costs are typically paid per month or year). Fixed costs must be funded regardless of the amount of waste collected and cannot be rapidly adjusted in response to a reduction in waste collection tonnage. Fixed costs can also be categorized as indirect or overhead costs. The high fixed cost component characteristic of municipal waste services is a powerful constraint on municipalities wishing to introduce quantity-based tariffs. This important aspect is considered in greater detail in the main text.

Indirect costs

Indirect costs are costs which relate only indirectly to the physical activity of providing municipal waste services. They relate to costs incurred in providing the support services on which the technical operations depend. They can include personnel, accounting and payroll, legal, financial control and management, purchasing, fee collection, data processing, records management, and executive oversight (the mayor's salary and office expenses). Indirect costs typically constitute a significantly smaller component of total costs than the direct component.

Investment expenditures

Investment expenditures of primary interest to this document are initial investment expenditures and reinvestment expenditures necessary to replace assets at the end of their useful economic lives. Future investments planned to expand the scope of services are not considered within the scope of the current material.

The main investment categories represented in municipal waste management systems are as follows:

- Collection infrastructure (vehicles, bins, offices, and maintenance facilities)
- Transfer facilities (transfer stations, storage capacity, and haulage vehicles)

- Treatment facilities (sorting plants, composting plant, and equipment)
- Disposal facilities (landfill and equipment).

The main asset categories for depreciation purposes are typically:

Waste containers	3–7 years life
Vehicles	7–10 years life
Plant and equipment	10–15 years life
Civil works	20–40 years life (normally limited by facility life).

Investment expenditures should include land purchases, planning and design fees, and supervision costs incurred during construction and implementation.

Waste management systems are characterized by

- Periodic replacement of plant and equipment (for example, waste collection bins, waste haulage vehicles, plant, and equipment)
- Periodic closure[147] of landfill cells and the construction of subsequent cells
- Closure and long-term care of the landfill site itself at the end of its operational period.

These costs are reflected in a continuous flow of investment expenditures over the life of the waste management system. They can be high and should be recognized and planned during the feasibility and financial planning stages. They have a major impact on the annual revenue required to operate the system on a financially sustainable basis and consequently on the size of user charges.

Landfill and landfill cell closure costs should be recognized and paid for by users in advance over the life of the cell or landfill. This reflects the user pays principle that costs should be borne by those who give rise to the costs. For example, the need for landfill cell closure is created by the users who deposit waste into and use up the capacity of the landfill cell.

Liabilities

Most capital assets are created at a point in time and are then progressively used up in future years over the assets' life. A collection truck is an example. For such an asset, annual depreciation (as described above) is used in the calculation of annual system costs, budgets, unit costs and tariffs.

Note that liabilities (future cash outlays[148] or expenditure obligations) created as the result of current operations must also be accounted for. The need to finance the closure of a landfill cell is an example. The act of operating a landfill cell creates the future liability of having to close it. The future costs of closing the cell are thus directly attributable to current users and should be recognized in the current tariff structure accordingly. Similarly, employee retirement benefits, such as pensions and health care, are future outlays obligated by current employee services.

A future outlay can be converted into a cost using the established financial technique of amortization. Amortization refers to any process of liquidating a debt over time. The amortization of future outlays for landfill closure and post-closure care recognizes that cost over the period of landfill operation.

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[147] The costs of investments in landfill cell closure should be borne by the users of the cell being closed. That is, they should be covered by the users of the cell in advance of it being closed. This key factor is often not recognized in waste management planning.

[148] A future outlay is an expenditure of cash in the future that is obligated by current or prior activities.

That is, future expenditures incurred to close the initial landfill cell are directly attributable to the waste generators which deposited waste into the cell. In a full cost recovery policy, provision for current users to fund such liabilities would be made through the tariff mechanism. Similarly, future expenditures to rehabilitate and monitor a landfill at the end of its life should also be funded in advance by all landfill users over its operating life according to the amount of waste each has disposed of to the site.

In this process, provision is made through the tariff mechanism to accumulate sufficient funds to finance a liability when it becomes due. This is achieved by including in the cost analysis annual provisions which, when accumulated over the life of the liability, generate sufficient funds to liquidate the liability. Unlike depreciation—by which the value of an investment is recovered over its projected life—prepayments are collected in advance of the investment expenditure. Such provisions should be recognized in the calculation of the annual revenue requirement and reflected in the average tariff.

This is particularly important when planning the tariff in the early years of strategy implementation, where provision should be made at a minimum to generate the funds needed to close the first landfill cell from the users of that cell. Ideally, provision should also be put in place for landfill closure and its post-closure monitoring and care.

O&M Costs

Operating costs are the recurrent costs incurred over relatively short periods of time (less than one year) in operating and maintaining the assets of a business. They typically include the following:

- Personnel wages and salaries (including overheads)
- Building, vehicle, and equipment maintenance
- Material and energy costs: power, fuel, chemicals, and similar materials
- Rent, leases, insurance, and licences
- Contract services
- Operational overheads and administrative expenses.

Maintenance costs are sometimes shown as a percentage of the initial investment cost of the asset being maintained. Estimates such as these might be used at the system planning stage, although other sources of information (such as from the bidding documents of prospective third-party partners, from the practical experience of senior staff, or from consulting engineers) might also be used at the planning stage. Practical experience and data gained during the operational phases of similar systems should however be drawn upon wherever possible.

O&M costs are typically adjusted over the operational period for annual changes in the amount of waste being managed and for real increases in the cost of labor. Factors such as these can result in large increases in operating costs (before inflation) over the planning, investment and operational periods.

Values used when projecting O&M costs should be realistic, drawing on a range of potential sources. These include existing operational experience (current and projected future labor costs, for example); plant and equipment manufacturers' specifications and guidance; informed judgment of advisers and operators; local and international experience; publicly available material. The objective must be to provide a realistic assessment of future costs—it should not be to minimize costs unreasonably to justify a preferred outcome.

Overhead costs

Overhead costs are the management and support costs a municipality incurs in providing municipal SWM services. The costs of management and labor support should be fully accounted for, together with a proportionate share of office costs (for example, rent, office equipment, and utilities) incurred. They are effectively a subset of indirect costs.

Present Value

The current value of a future stream of cash flows given a specific discount rate (or rate of return). See Annex 2 on DCF analysis.

Residual Value of Investment (Capital) Assets

'Residual value' is the value remaining of an asset in the final year of the assessment period after taking depreciation up to that point into account. It is the value of the unused portion of a capital investment and is treated as a project revenue or benefit when calculating the net cash flow. For example, landfill plant and equipment and collection vehicles may retain some economic value at the end of the period. Residual value is a revenue component and not a cost component. Recognizing it in the cash flow effectively adds back the unused value of the assets. Residual value is calculated as the starting value of the assets (investments) minus the depreciation accrued at the end of the assessment period.

The residual value of assets after depreciation is entered into the final year of the analysis period and is a key factor in net cash flow calculations based on DCF analysis. It is calculated as the difference between total investments over the analysis period and total depreciation over the same period. It represents the remaining value of the assets and is added back as a revenue input at the end of the assessment period.

Return on Investment

ROI is a project cost—a cost that must be recovered if investors are to be compensated for investing in a project (and if resources are to be attracted to the project). It is included in the calculation of the annual revenue requirement when using the TA approach to unit cost and tariff setting. It is not included in the AIC approach, as the discount plays this role there.

The ROI is calculated as a percentage of the average value of an asset for each year of the asset life. The opening value of an asset is equal to its closing value in the previous year. The closing value of an asset is calculated as the opening value plus investment expenditure in the current year minus depreciation in the current year. The ROI is calculated as the average value (opening value plus closing value divided by 2) multiplied by the expected ROI. ROI in this analysis is taken to be the same as the discount rate used in DCF analysis.

Transfer payments

Transfer payments are funds provided by local, state, or national governments to part-fund the investment and operating costs of the waste management services being provided. They are also known as municipal transfers or subsidies. They are sources of grant funding. International grant funding could also be considered to fall into this category.

Variable costs

Variable costs are costs that change as the volume changes. A key example of this is landfill gate fees, where the total charge varies directly with the quantity of waste disposed of. This important aspect is considered in the main text.

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