Planning Tools and Procedures for Rational Municipal Solid Wastes Management

Alexander P. Economopoulos

Abstract A rational approach for developing optimal municipal solid wastes (MSW) management plans comprises two steps, the strategic and the detailed planning one. The objectives of the strategic planning are the screening of alternative technologies, the definition of the number and approximate location of sites for treatment and/or disposal installations, the formulation of alternative management plans and the selection of the most prominent ones. The detailed optimal planning, which normally follows, focuses on the latter and develops the plan that meets all legal and other requirements with the least cost. In addition, it performs sensitivity analysis involving the development of alternative optimal plans, each of which meets a set of constraints. The latter reflects the preferences and/or objections of the communities concerned (e.g. the exclusion or imposition of sites and/or technologies, the application of capacity limits etc.). The local authorities can then select among the alternative plans the one, which balances best their preferences and objections against the associated costs.

1 Introduction to MSW Management

The diagrams in Fig. 1 illustrate the evolution of the waste management schemes, from a typical initial to a more advanced stage. The management in its initial stage is often limited to the source separation of some recyclable materials and to the landfilling of the remaining wastes, Fig. 1a. In more advanced stages, a portion of

A. P. Economopoulos (✉)
Environmental Engineering Department,
Technical University of Crete,
731 00 Chania, Greece
e-mail: eco@otenet.gr

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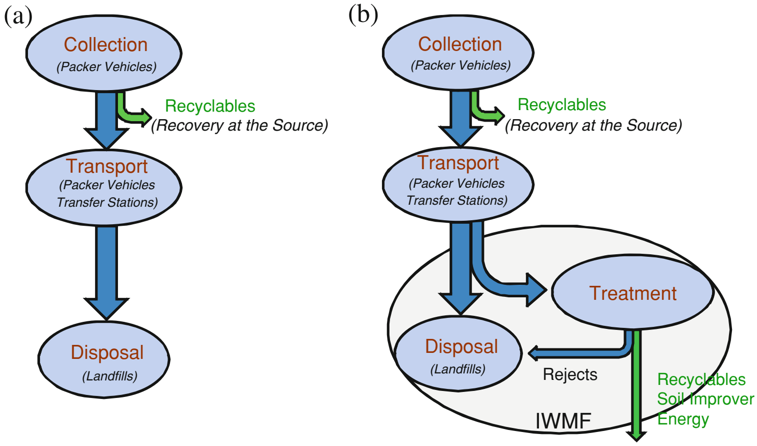


Fig. 1 Evolution of the MSW management system from an initial to a more advanced stage

the commingle MSW is treated so as to recover recyclable materials, to produce biostabilized organics (used as soil improver or landfill cover material) and/or to generate energy. From the treated MSW only the rejects are landfilled, Fig. 1b.

In the most advanced management stages, emphasis is given on the waste prevention, reuse and source separation into selected streams (e.g. recyclable material and/or kitchen waste streams). This improves the yield and the quality of the waste products and reduces the treatment and final disposal requirements.

The treatment and final disposal of the wastes take place in integrated waste management facilities (IWMFs). These, usually serve areas with large populations so as to achieve the desirable economy of scale. The collection of the wastes to central IWMFs often involves distant transportation of the MSW and this is economically achieved through transfer stations than make optimal use of road, railroad and sea transportation media.

In the general case, treatment of the MSW through successive steps at different installations may be involved and final disposal of the rejects at different sites may be required, depending on the nature of the rejects. Moreover, the IWMF can be physically distributed at different sites, each hosting one or more of the required installations. Some of the above possibilities are discussed in Sect. 4.1.

2 Overview of MSW Management Technologies

The purpose of this section is to outline the technologies often used in the transportation, treatment and final disposal of MSW and to provide relevant data and information required for the formulation and evaluation of alternative management plans.

Fig. 2 Transfer station with a ramp, a hopper and a semitrailer under the hopper in loading position

2.1 Transfer Stations

As the quantities of the MSW grow and the travel distances to their management facilities increase, the cost of direct transportation by the collection vehicles becomes increasingly expensive. From a point onward, the transportation becomes more economic though the use of transfer stations. The latter receive the waste of collection vehicles and transfer it to large trucks, tractor-trailers, semi-trailers, railroad cars and/or barges for economic long distance transportation.

Transfer stations without waste compression are the simplest to construct and require limited investment. However, most modern transfer stations provide waste compression, as this reduces the transportation costs enabling the howl vehicles to transport heavier net pay loads. The latter are usually of the order of 19.5 t, but this depends on the applicable gross weight limits of the roads and on the vehicle design and configuration. Two of the most frequently used transfer station technologies are described in the Sects. 2.1.1 and 2.1.2 that follow.

2.1.1 Transfer Station with Mobile Compactor Units

In a typical station of this type, the packer vehicle ascent to an elevated platform through a ramp, so as to discharge their wastes into a hopper. From there, the wastes are fed to the front end of a container fixed on a semitrailer, Fig. 2. The container is equipped with a hydraulic pusher mechanism, which facilitates (a) the waste loading by pushing periodically the wastes towards the back-side of the container, providing at the same time a degree of compaction, and (b) the waste unloading at the waste reception site.

Fig. 3 Transfer station with a hopper, a compactor unit and semitrailers for the transportation of containers

2.1.2 Transfer Stations with Compactor Units

As in the previous case, the packer vehicles ascent to an elevated platform through a ramp so as to discharge their wastes into hoppers for temporary storage. From there the wastes are fed into compactors and are compressed into containers. The latter are loaded into large trucks or semitrailers for transportation to the reception site, Fig. 3. When large quantities of wastes are to be transported to remote IWMFs, the transportation of containers through railroad or sea can be more economic. In these cases, the direct loading of the containers from the transfer station into railroad cars, as in Fig. 4, or into barges is particularly cost effective.

2.2 Treatment Methods

The technologies considered in the present section are suitable for the treatment of commingled MSW, as their use is expected to remain predominant for several years in countries with a short history in material separation at the source programs. Four such commonly used technologies are briefly described below.

The material and energy balances presented in the diagrams of Figs. 5, 6, 7 and 8 and Table 1 are indicative and correspond to the anticipated mean composition of the waste feedstock (the wastes that remain after the application of material recovery at the source programs) in Greece.

2.2.1 Aerobic Mechanical:Biological Treatment

The Aerobic Mechanical-Biological Treatment (MBT) comprises a material separation unit followed by an aerobic composting one, Fig. 5. The former can

Fig. 4 Transfer station with direct loading of containers to train

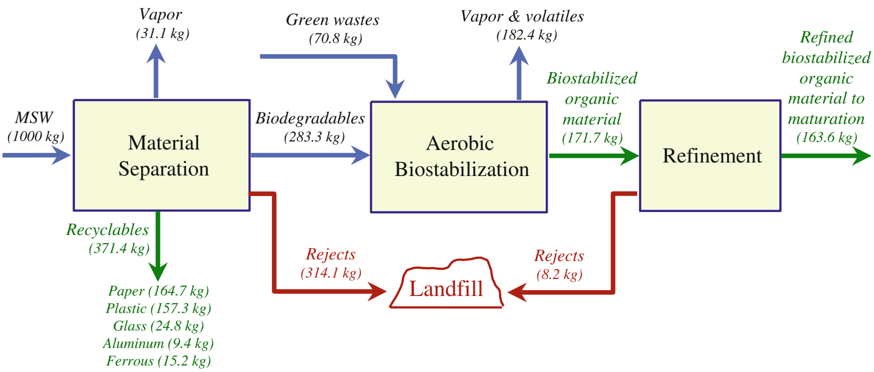


Fig. 5 Typical flow diagram of Aerobic MBT plants with indicative material balances (*Source* Economopoulos [8])

recover recyclable materials (paper, plastic, glass, metal etc.) and/or RDF (Refuse Derived Fuel) and separate the remaining wastes into organics and rejects. The organics, mixed in proper proportions with green wastes (and optionally with wastewater sludge), are fed into the aerobic composting unit, in which they are adequately aerated and biostabilized. The product can be used directly as disturbed soil improver (eg. in quarries) or as landfill cover material.

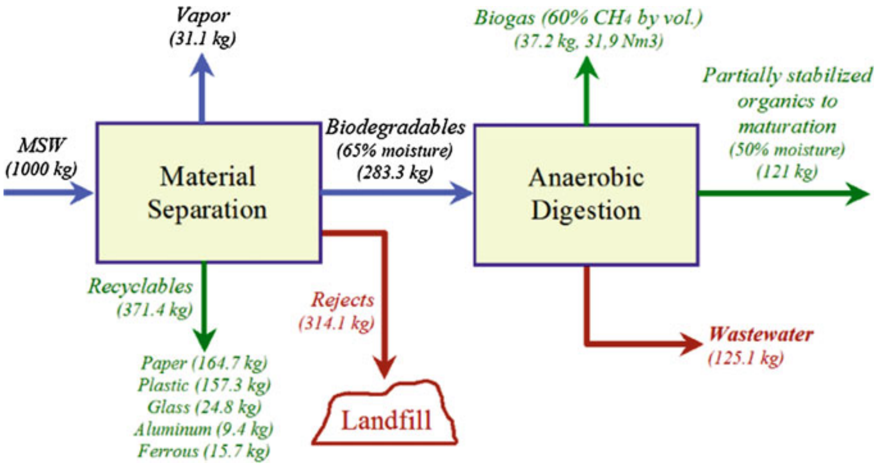
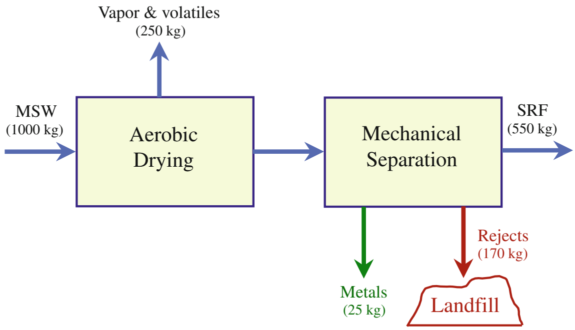


Fig. 6 Typical flow diagram of Anaerobic MBT plants with indicative material balances (*Source* Economopoulos [8])

Fig. 7 Typical flow diagram of biological drying plants with indicative material balances (*Source* Economopoulos [8])



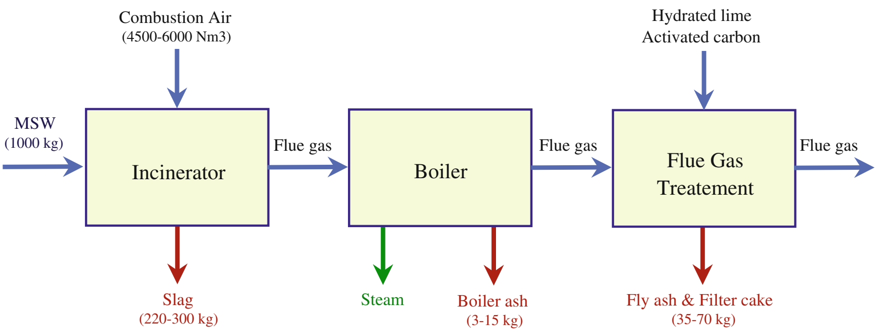


Fig. 8 Typical flow diagram of waste incineration plants with indicative material balances (*Source* Economopoulos [8])

Table 1 Electric energy export potential of alternative treatment methods [8]

Aerobic MBT with materials recovery		
Internal energy consumption	kWh/1,000 kg MSW	**32,0**
Excess electricity to be exported	kWh/1,000 kg MSW	**−32,0**
Biological drying and incineration of SRF		
Biological drying:		
Secondary fuel production	kg SRF/1,000 kg MSW	550,0
LCV of fuel	MJ/kg SRF	17,5
Internal energy consumption	kWh/1,000 kg MSW	**140**
SRF incineration:		
Overall conversion efficiency	%	27,0
Electricity generation	kWh/1,000 kg MSW	**721,9**
Internal electricity consumption	kWh/1,000 kg MSW	**197,8**
Excess electricity to be exported	kWh/1,000 kg MSW	**384,1**
Mass incineration		
Feedstock	kg MSW	1000,0
LCV	MJ/kg MSW	11,5
Overall conversion efficiency	%	20,0
Electricity generation	kWh/1,000 kg MSW	**640,0**
Internal electricity consumption	kWh/1,000 kg MSW	**175,4**
Excess electricity to be exported	kWh/1,000 kg MSW	**464,6**

2.2.2 Anaerobic Mechanical: Biological Treatment

The Anaerobic MBT method, illustrated by the flow diagram of Fig. 6, differs from the Aerobic MBT one in that the organic fraction undergoes anaerobic (in enclosed reactors, without oxygen), instead of aerobic, decomposition.

Most of the anaerobic systems today are of the high solids (with the feedstock diluted with water to a total solids content of around 25%), thermophilic and single-stage type, with retention times ranging from 14 to 20 days.

The stabilized residues contain large amounts of water, most of which is removed by filtration. Only a portion of the removed water can be reused so as to maintain the electrical conductivity within proper limits in order to protect the microbial activity in the reactors. The excess water forms a strong effluent that requires advanced treatment prior to disposal. The filter cake can be matured under aerobic conditions for a period of 2–4 weeks.

2.2.3 Biological Drying

The biological drying, a pretreatment process that converts the MSW into SRF (Solid Refuse Fuel—a secondary fuel), comprises waste shredding, aerobic drying for reducing the moisture of the wastes to less than 20%, metal recovery, and separation of rejects, Fig. 7.

The energy required for drying the wastes in the bioreactor is generated by the exothermic aerobic decomposition of a limited fraction of easily biodegradable organics. This process does not biostabilize the wastes and is in fact designed to minimize the bio-decomposition so as to preserve the energy content of the wastes.

2.2.4 Incineration

The waste incinerator plants comprise the incinerator, usually of the inclined moving or roller grate type, the boiler for energy recovery and electricity production, and the flue gas treatment system for the removal of particles, HCl, HF, SO_2 dioxins, furans and heavy metals, including Hg, Fig. 8.

Most of the solid residues are generated from the combustion chamber and the boiler. Smaller, but more toxic, quantities are generated from the flue gas treatment system. In EU, the control of emissions is subject to Directive 2000/74. Guidance on pollution prevention and control is given by the BREF report, European Commission [14].

2.2.5 Electric Energy Balances

Table 1 presents typical electric energy balances for the above technologies, assessing their net electric energy export potential on the basis of their electric energy generation and internal consumption potential, Economopoulos [8].

2.2.6 Treatment Products and Possible Uses

All products from the treatment methods considered above can find a market (some, such as glass and biostabilized organics, at nearly zero or even slightly negative prices) with the exception of the SRF from the biological drying plants and the RDF from the Mechanical Separations Units, the alternative uses of which are illustrated in the diagram of Fig. 9.

The use of the SRF in the clinker kilns of the cement industry is a rational option, as no new installation is involved and little pollution is generated; The cement industry however, can accommodate small quantities of this fuel, e.g. Juniper Consultancy Services Ltd. [16]. Co-firing of SRF with fossil fuels in utility boilers is feasible, but in limited proportions due to operating problems. This however is not a practical option as the flue gas control system of the power plant needs to be upgraded to waste incineration standards and the toxic residues from the SRF incineration are mixed with large quantities of fly ash making the management of the latter expensive. As a result, incineration is the only practical SRF utilization method, Economopoulos [8]. Similar is the situation with the RDF, a secondary fuel, which can be optionally produced by aerobic or anaerobic MBT plants (see Sect. 2.2.1).

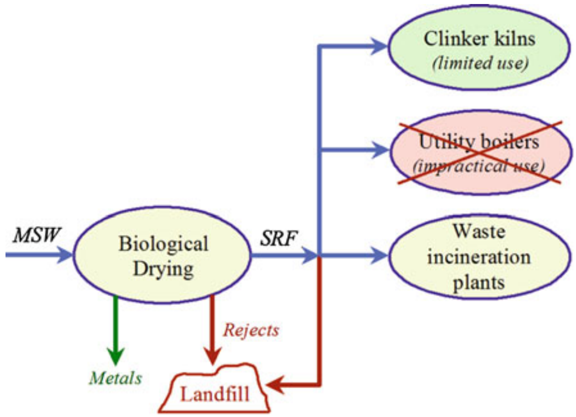


Fig. 9 Possible uses of the SRF produced from biological drying plants (adapted from [8])

2.3 *Final Disposal Sites*

In modern landfills the design comprises a low permeability liner to restrict leachates, a strong effluent, from percolating through the base of the landfill and a pipe system enabling collection of leachates for proper treatment and disposal. It comprises also a pipe system for collecting most of the biogas generated by the anaerobic decomposition of the organic materials so as to be flared or used for energy generation. Thus, modern landfills are not very simple facilities.

3 Planning Tools

The present section describes a graphical method that allows convenient determination of the approximate number and location of the required IWMFs in the study area. It provides also cost functions that allow economic analysis of management plans. The above are essential tools used in Sects. 5 and 6 for the formulation, evaluation and optimization of management plans.

3.1 *Optimal Number and Location of IWMFs*

For the development of cost-effective plans, planners need to define the near optimal number and the approximate location of sites for building the required waste treatment and final disposal installations. The above reflect the optimal balance between the economy of scale offered by large central installations and the increased cost of waste transportation required for collecting the wastes to these installations.

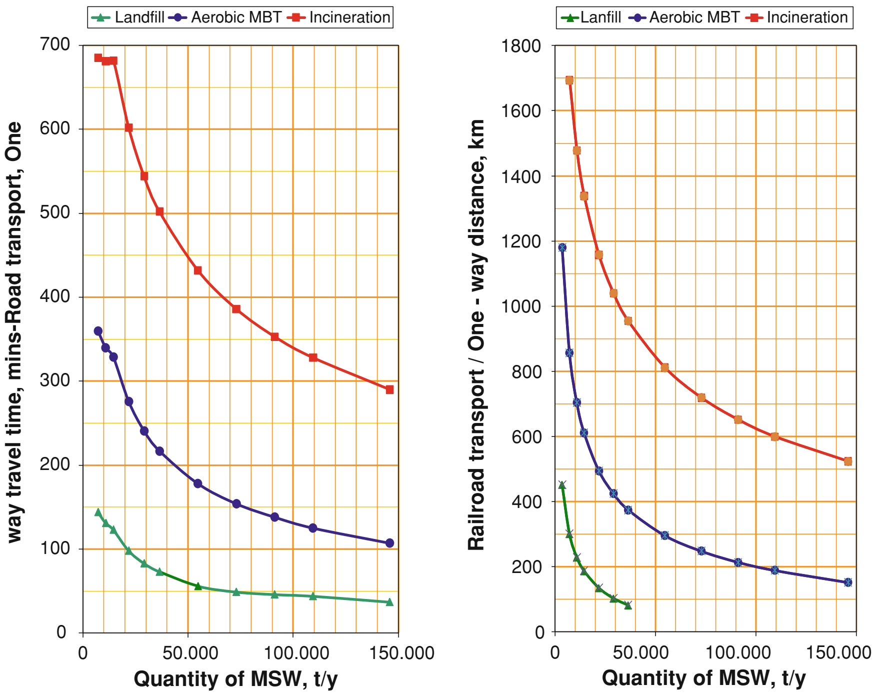


Fig. 10 Maximum time of road and maximum distance of rail transport to central IWMF as function of the quantity of local wastes, in case where a transfer station is already used

To cope with this requirement, an easy to use methodology is presented, which is based on the graphs of Figs. 10 and 11, Economopoulou and Economopoulos [11]. These graphs provide the maximum distance that is profitable to transport the locally produced wastes for treatment and/or disposal at a large central rather than at a small local IWMF. At this maximum distance, the extra cost of transportation becomes equal to the cost savings realized by the increased economy of scale of the large central over the small local IWMF.

The development of the graphs in Figs. 10 and 11 is based on the combined use of cost functions that yield the capital investment and annual operating costs of collection vehicles, transfer stations and their haul vehicles, treatment plants and final disposal installations. Updated graphs will soon be available based on the use of more recent cost functions, Economopoulou and Economopoulos [12].

As the graphs in Figs. 10 and 11 show, the maximum distance depends on the kind of treatment method considered, the quantity of local wastes, the transportation media (road or railway) used, as well as on the availability of local transfer stations.

In relation to the latter, two alternatives are considered: (a) Local transfer stations do not exist and are not required for transporting the wastes to the local IWMF. In this case, transfer stations may have to be constructed for the transportation of the

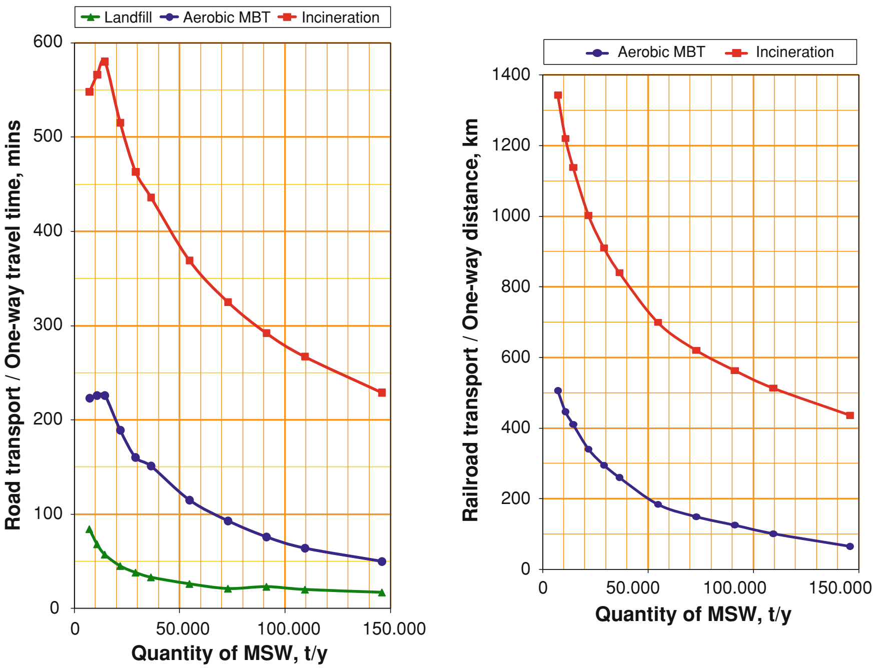


Fig. 11 Maximum time of road and maximum distance of railroad transport to a central IWMF as function of the quantity of wastes produced locally, in case where a transfer station is not used

wastes to the central IWMF and, if this is the case, the transportation cost must include the annual capital investment and operating cost of the transfer station, along with its temporary storage facilities and haul vehicles, and (b) Local transfer stations already exist and/or are required for the transportation of the wastes to the local IWMF. In this case, the same transfer stations can be used for transporting wastes to the central IWMF and hence, only the annual capital investment and operating cost of the haul vehicles for the extra transportation time need to be considered.

For road transportation, the graphs yield the maximum one-way driving time. This needs to be multiplied by the mean vehicle velocity for obtaining the one-way transportation distance. For railroad transportation the graphs yield directly the maximum one-way distance.

With the use of graphs in Figs. 10 and 11, planners can assess the approximate number and location of the required IWMF sites though the following steps:

1. Consider the administrative levels of the study area (e.g. municipality, prefecture) and select the one, which divides the study area in a reasonable number of sectors, e.g. 10–50.
2. For each administrative sector calculate the annual waste load generated (see Sect. 5.1), define its barycentric population point, use the graphs in Figs. 10 or 11 for estimating the maximum transport distance for the desirable

treatment method, and draw a circle around the barycentric point with a diameter equal to 0.8–0.9 of the maximum transport distance.

3. The overlay areas of surrounding circles define the possible location of a central IWMF that can serve the corresponding administrative sectors. As most administrative sectors can be served by a number of alternative central IWMFs, planners can define the location of IWMFs and group the administrative sectors served by each IWMF in many different ways. The following provide some guidance for making rational selections:

- Administrative sectors are served best by central IWMFs with good road connection.
- The use of overlay areas with sites- or near sites- known to be particularly suitable (e.g. large mine fields or sites already in use) should be given priority.
- The selections should be in the direction that equalizes the load distribution among central IMWFs.

In some cases, the same exercise could be repeated with the exclusion of congested administrative sectors with very large populations. This exclusion is of practical interest in cases where it is difficult to find proper sites within- or near- the congested administrative sector and it is justified by the fact that transportation of the wastes from the congested sectors to sites at reasonably long distance is not prohibitively expensive.

It is interesting to note, that alternative sets of sites, defined through different selections in the above procedure, are likely to lead into optimal solutions with nearly identical total management costs.

3.2 Normalized Cost Elements

In the present section, typical cost data are given for waste treatment, transportation and final disposal installations, so as to enable the economic analysis of management plans.

3.2.1 Cost of Treatment

For plants with configurations similar to these in the diagrams of Figs. 5, 6, 7 and 8, cost functions allowing estimation of the initial capital investment and annual operating cost versus the annual quantity of MSW processed, have been developed and presented in graphical and mathematical form, Economopoulos [8].

For the Aerobic MBT plants, the cost data have been generated by an advanced plant design and cost estimation model and have been found in reasonable agreement with cost data reported in the literature from European plants. For the remaining processes, data were collected from recent EU literature sources.

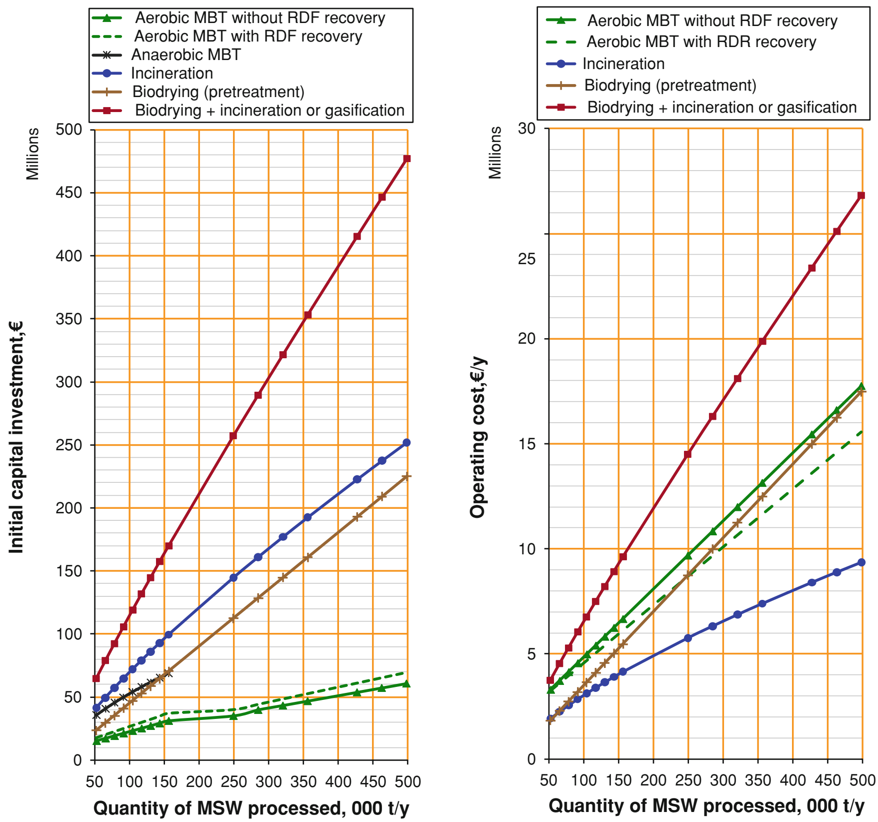


Fig. 12 Initial capital investment and annual operating cost of alternative waste treatment technologies (*Source* Economopoulos [8])

The datasets thus established were fit so as to derive cost functions for the initial capital investment and the annual operating cost of alternative treatment technologies and the results are presented in the diagrams of Fig. 12.

As it can be seen from the above diagrams, the biological drying plans do not offer any significant economy of scale; this is due to their modular construction and the use of multiple parallel units in large installations. It can be also noticed that the total cost for the biological drying of the wastes and the SRF incineration of the SRF produced, is considerably higher than that of the direct mass incineration of MSW.

The capital investment and operating cost functions of Fig. 12 have been used for deriving the normalized treatment cost functions presented in the graphs of Fig. 13. The latter are based on the following two typical scenarios:

(a) The plant is owned and operated by a municipality association. In this case the annual cost of the invested capital is assumed 5.5% and the average life of the installation 20 years (zero salvage value). As the plant provides service to its Municipality members, VAT is not charged.

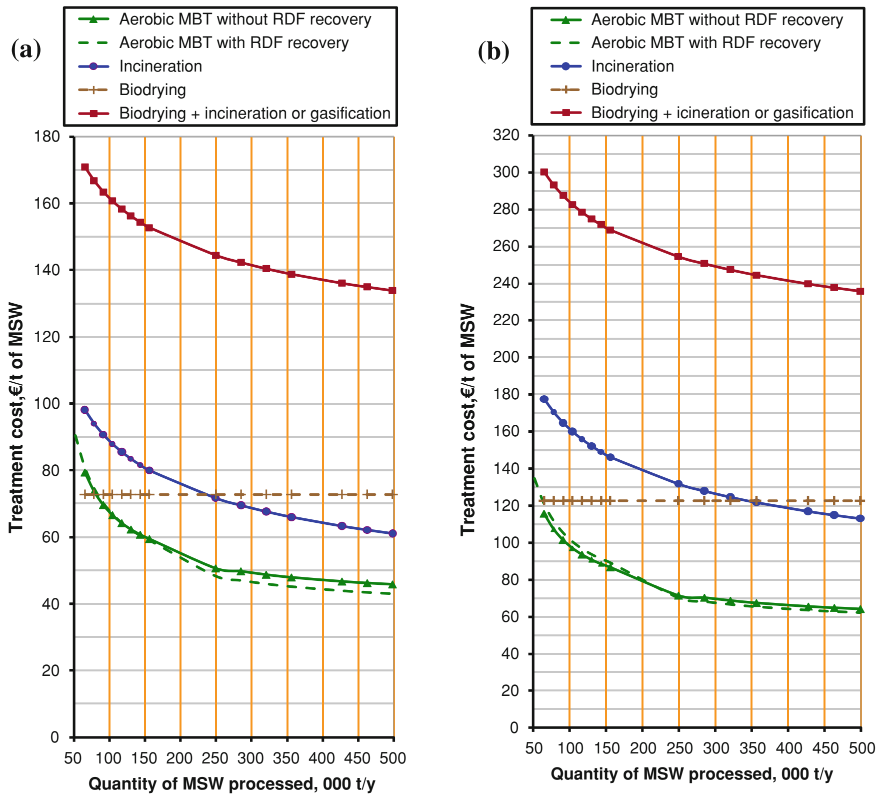


Fig. 13 Normalized treatment costs of alternative technologies with plants built and operated by **a** municipal associations, and **b** private enterprises (Economopoulos) [8]

(b) The plant is built and operated by private entrepreneurs. The annual internal return on investment is assumed 14% and the average life of the installation 20 years (zero salvage value). In this case, the gate fees include 19% VAT.

The graphs of Fig. 13 yield the normalized treatment cost (in €/t of MSW processed) for the alternative technologies considered in Sect. 2, as well as for the biological drying of MSW and the gasification or incineration of the SRF produced.

The treatment costs in Fig. 13 refer to year 2009 and do not include the revenue from the sale of products (recyclable materials and/or energy), nor the expenditures for the transportation and management of unused products and residues. However, the material and energy balances in the diagrams of Figs. 5, 6, 7 and 8 provide data about the quantities of products and rejects, facilitating the estimation of the relevant annual revenues and expenditures.

It should be noted that the cost functions of Fig. 12 are based on data obtained, mostly, from literature. As such they are approximate and do not take into consideration the particular conditions that influence the actual cost of each installation. Moreover, the treatment cost functions of Fig. 13 are based on the specific assumptions associated with each scenario considered. Different assumptions result to different treatment cost functions.

3.2.2 Cost of Transportation and Final Disposal

Cost functions for assessing the capital investment and annual operating costs of transfer stations and final disposal sites are not yet available. They are getting however developed and will be presented elsewhere, Economopoulou and Economopoulos [11].

As a rough guide, the normalized capital investment and operating costs for the road transportation of the wastes to a central IWMF is in the order of 30 €/t/y and 33 €/t respectively for regions with a surface area of about 12,000 km^2 and 50 €/t/y and 72 €/t respectively for regions with a surface area of 60,000 km^2, Economopoulos [7].

3.2.3 Revenue From the Sale of Products

The revenue from the sale of recyclable materials recovered and/or electricity produced can be estimated on the basis of the material and energy balances of the treatment processes used (such as these in Figs. 5, 6, 7 and 8 and Table 1) and the market prices of these products.

An example estimation of the anticipated income from the operation of an Aerobic MBT plant is presented in Table 2.

The estimation is based on the material recovery factors listed in the diagram of Fig. 5 and on the recyclable material prices in the Greek market during August 2008 and March 2009. In this example, the significant drop in the recyclable material prices due to the economic crisis, reduced the anticipated plant revenue from 32.1 to 11.8 €/t of MSW.

3.2.4 Income From Incentives

Financial incentives are offered by some countries for promoting specific management objectives. These may affect the net cost of treatment and the comparative economic evaluation of alternative treatment methods and need to be taken into consideration.

In Greece for example, the incentives offered for the recovery of packaging materials from the MSW could generate a revenue to aerobic or anaerobic MBT plants as high as 22 €/t of MSW treated, Economopoulos [7]. It is interesting to note that the combined revenues from the sale of products (see Sect. 3.2.3) and the incentives mentioned above, could cover most of the treatment cost in aerobic MBT plants in Greece (Fig. 13).

Table 2 Normalized income from the sale of recyclable materials recovered from Aerobic MBT plants [7]

	Price, €/t of recyclable material		Recovery	Income, €/t of MSW	
	August-08	March-09	kg/t of MSW	August-08	August-08
Paper	55.8	17.6	164.7	9.19	2.90
Plastics	114	34.6	157.3	17.93	5.44
Metals	201	141	24.6	4.94	3.47
Glass	0	0	24.8	0.00	0.00
Overall	86.34	31.80	371.4	32.07	11.81

4 Scope and Purpose of Management Plan Optimization

The objective of this section is to address the questions of what is to be optimized, why optimization is required and how optimal plans can be developed.

4.1 Alternative Management Options

The diagram of Fig. 14 illustrates a number of management alternatives based on the treatment technologies presented in Sect. 2.2. More specifically:

- Recyclable materials, such as paper/cardboard, plastic, metal and/or glass, separated at the source, can be reused or recycled with minimal processing.
- The commingled MSW that remain can be treated in aerobic or anaerobic MBT plants so as to obtain recyclable materials and/or RDF and biostabilized organics. The inert residues can be landfilled. If RDF is produced, it can be used by waste incineration plants and (in limited quantities) by the clinker kilns of the cement industry.
- The aerobic MBT plants can be designed so as to accept source-separated recyclable material streams into their material separation units and source-separated kitchen and garden wastes into their biological stabilization units. This way, plants built for treating commingled MSW can also accommodate source-separated waste streams as their quantities increase with time.
- Alternatively, the comingled MSW can be processed, along with SRF or RDF, in waste incineration plants, possibly after the recovery of some recyclable material at material separation units. The exported energy can be in the form of electricity and/or heat for space heating or industrial use. The residue (grade ash, boiler slag, and fly ash or filter cake from the flue gas treatment system) contains toxic substances and need to be disposed of at appropriate facilities.
- The comingled MSW can also be pretreated in biological drying plants, possibly after the recovery of some recyclable material at material separation units. The SRF produced can be incinerated and/or used (in limited quantities) in the cement industry. The inert residues are landfilled.

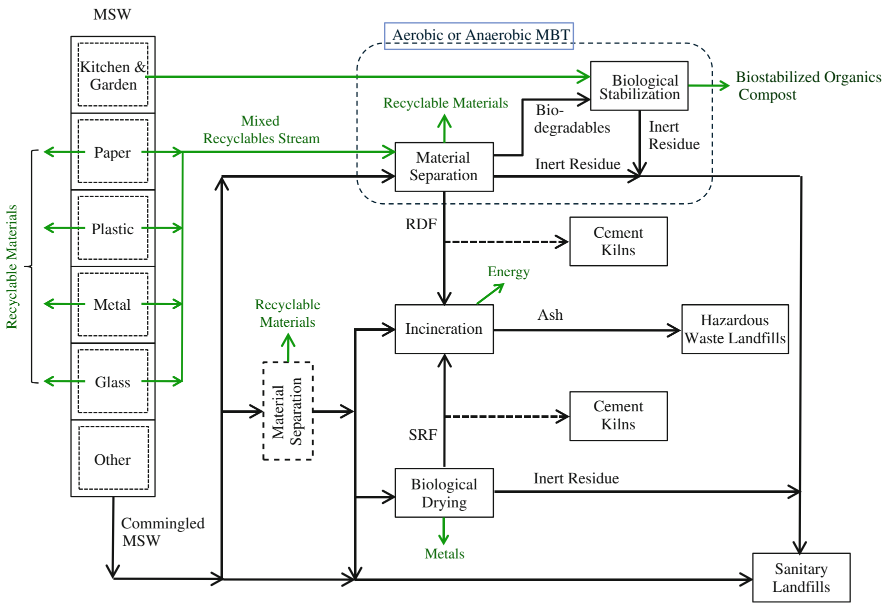


Fig. 14 Waste flows in alternative management plans based on the treatment technologies presented in Sect. 2

The options illustrated in the diagram of Fig. 14 and outlined above are not exhaustive as additional treatment methods exist (e.g. gasification, pyrolysis). Moreover, for most treatment methods, a number of alternative technologies exist, each with its own product types and qualities, product yields and economics.

Each management plan developed by planners can be represented by a waste flow diagram, similar to that of Fig. 14, but simpler in form. In this diagram, planners can perform material and energy balances for each type of installation, or each individual installation (see for example Sect. 5.5), which are essential for the evaluation of the plan under consideration (see Sect. 5.6).

4.2 *Scope of Plan Optimization*

The number of the alternative waste management options and their combinations are numerous, as illustrated by the waste flow diagram of Fig. 14. Among them, planners have to select the ones that minimize the sum of the annualized capital investment and annual operating costs of all transportation, treatment and disposal operations, taking into consideration the income from the sale of products and the possible financial incentives offered. Moreover, planners have to define the optimal location, type, size and operation of each transfer station, pre-treatment, treatment and final disposal installation, as well as the flow of the wastes, waste products and residues among them.

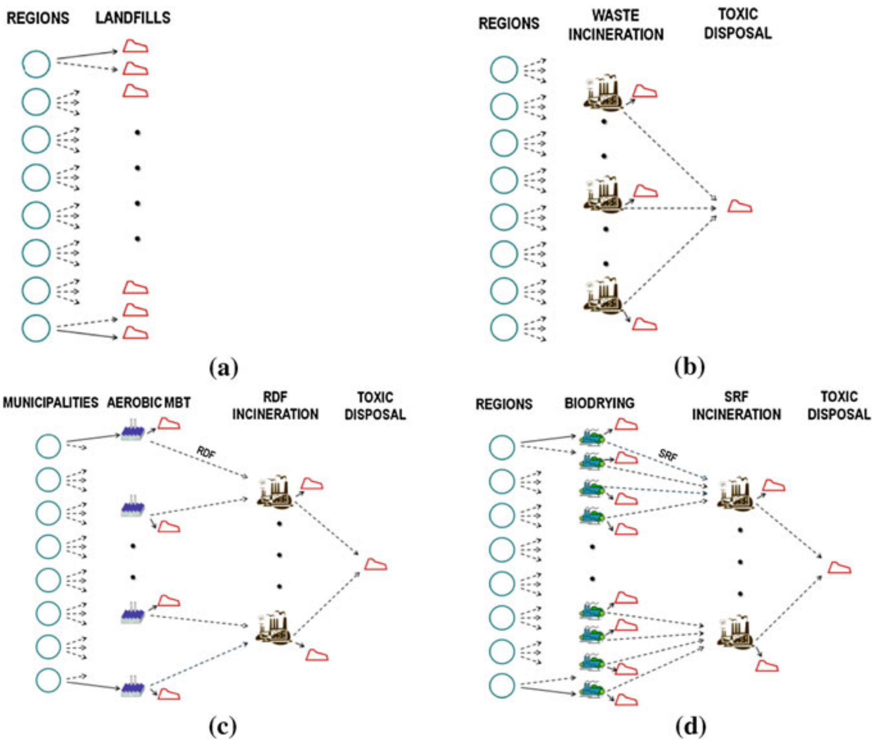


Fig. 15 Schematic representation of typical management plans involving **a** direct landfilling of the MSW, **b** direct incineration of the MSW, **c** aerobic MBT of the MSW and incineration of the RDF produced, and **d** biological drying of MSW and incineration of the SRF produced

The number, size and location of the installations reflect the optimal balance between the economy of scale offered by large central installations and the increased cost of waste transportation required for collecting the wastes to these installations. In order to illustrate this principle, let us consider four study areas with the management options illustrated in the diagrams (a)–(d) of Fig. 15.

Installations with strong economies of scale can optimally serve larger areas as they can compensate for higher transportation costs. Based on this:

- If landfilling is the sole objective of the MSW management, as in the diagram of Fig. 15a, a fair number of landfill sites are required as landfilling is a low cost operation offering limited economy of scale.
- If the wastes are to be incinerated, as in the diagram of Fig. 15b, a small number of plants is required, as they offer a strong economy of scale, and possibly fewer toxic waste disposal sites as the toxic wastes quantities generated are limited.
- If the wastes are to undergo aerobic MBT with RDF production and incineration, as in the diagram of Fig. 15c, a limited number of aerobic MBT plants are required, as they offer a fairly strong economy of scale. These have to be

combined with fewer RDF incineration plants and still fewer toxic waste disposal sites, as the RDF incineration plants offer strong economy of scale and the quantities of toxic wastes are limited.
- If the wastes are to be biologically dried and the SRF produced is to be incinerated, as in the diagram of Fig. 15d, numerous biological drying plants are required as they offer no economy of scale (they comprise parallel modules, each of which is capable of processing about 50,000 t/y of MSW) and as explained in the previous case, few SRF incineration plants and still fewer toxic waste disposal sites.

The above discussion serves to demonstrate that in all but the simplest cases, the development of optimal plans is a demanding task. As a result, planners can be significantly assisted by proper methodologies and software tools.

4.3 Purpose of Plan Optimization

Decision makers may wonder whether the effort required for the development of optimal plans is justified. In order to address this question, the costs and benefits of a relatively simple and a relatively sophisticated case study were reviewed and the conclusion was that the cost of proper planning represents only a small fraction of the annual cost savings it offers. This tends to be the rule and applies, not only when planners deal with large study areas and sophisticated management objectives, but also in cases of relatively small study areas and simple management objectives.

4.4 A Two-Stage Planning Approach

From the discussion in Sects. 4.1 and 4.2 it would appear that the development of optimal plans is, in most cases, a demanding operation. This is true, even in cases where appropriate software tools are available as the setup effort can be excessive. In view of this, a two-step approach has been developed, which comprises the strategic and the detailed optimal planning phases.

The strategic planning is based on the planning tools discussed in Sect. 3 and aims at the screening of alternative technologies, the definition of the number and approximate location of sites for treatment and/or disposal installations, the formulation of alternative management plans and the selection of the most prominent on the basis of their compatibility with the management objectives, cost, environmental problems and social acceptance characteristics (see Sect. 5). This exercise, which can be carried out reasonably fast and without the need for specialized software tools, provides valuable input to any relevant follow-up study.

The detailed optimal planning, which normally follows, focuses on the prominent management schemes identified in the previous phase and develops the plan that meets all legal and other requirements with the least cost. In addition, it performs sensitivity analysis involving the development of alternative optimal plans, each of which meets a set of constraints. The latter reflects the preferences and/or objections of the communities concerned (e.g. the exclusion or imposition of sites and/or technologies, the application of capacity limits etc.). The local authorities can then select among the alternative plans the one, which balances best their preferences and objections against the associated costs.

5 Development of Strategic Management Plans

The steps involved in the formulation of strategic management plans are illustrated in the diagram of Fig. 16 and outlined. A more detailed description, along with an application, is presented elsewhere, Economopoulos [7, 9].

5.1 Collection of Data and Information

For the formulation and analysis of strategic management plants, the collection of the following data and information is required:

- Data about the permanent population and the monthly visitors of the municipalities and communities in the study area over the design period. Future trend estimates are usually based on the analysis of relevant historical population and economic data and can be adjusted on the basis of development plans, Economopoulos et al. [10]. The main use of this information is for assessing the waste quantities and composition, as explained below.
- Data about the annual quantity of the wastes generated in each municipality and community and the typical composition of the wastes in each region over the design period. Estimates can be based on the analysis and extrapolation of past quantity and composition data, if they exist, Economopoulos et al. [10]. Alternatively, planners can use population data, along with typical normalized waste load and composition data from other similar regions of their country or relevant data from the literature, e.g. Eurostat [15], OECD [17], Riber et al. [18]. It is also possible to apply suitable statistical models, which provide waste load and composition estimates based on data and indices reflecting the present and future development of each region, e.g. Daskalopoulos et al. [4], Beigl et al. [1–3]. The required data and indices are usually available from the statistical services.
- Information about sites that could be particularly suitable for IWMFs, e.g. large lignite or bauxite mines. This information can be obtained from geological and other relevant services and is used in the IWMF sitting procedure discussed in Sect. 5.4.
- Definition of the existing management plan. This includes data on the quantities of recyclables recovered, on the location, design, capacity and function of all

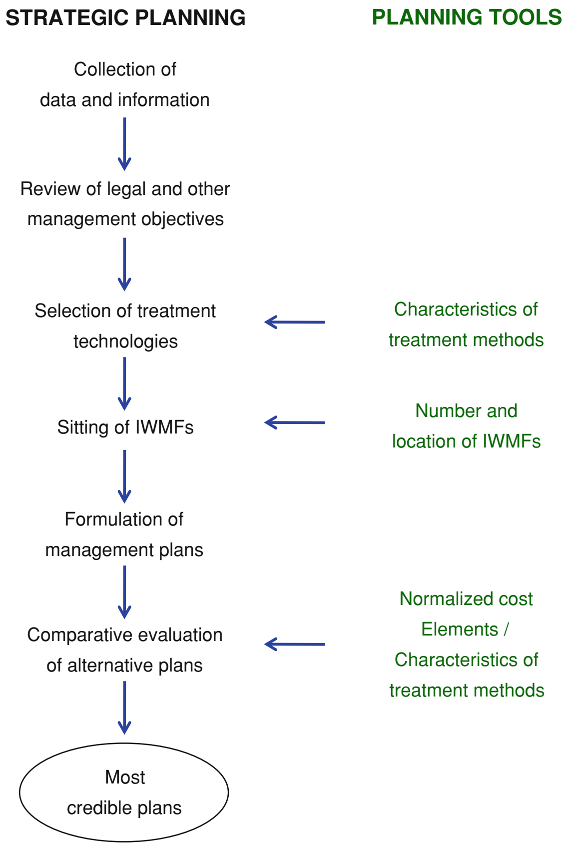


Fig. 16 Procedure for formulating strategic management plans

transfer, treatment and final disposal installations and the flow of the wastes among them.

5.2 *Review of Legal and Other Management Objectives*

In most countries there is legislation that defines the MSW management objectives. For example, in the European Union, the management of the MSW is controlled by a number of directives, such as Directive 1999/31, which stipulates the progressive reduction of biodegradable materials to be landfilled, Directive 2004/12, which stipulates the progressive recovery and use of the packaging wastes and the Directive 2008/98, which sets the hierarchy in waste prevention, management legislation and policy.

The applicable legislation in the study area must be reviewed and its stipulations must be quantified and expressed in a form compatible with the plan formulation procedure. If the legislative requirements are incomplete, outdated and relatively loose, planners can set additional requirements so as to improve the quality of management. Landfilling of the MSW is the minimum requirement for the protection of health and the environment. Prior to this, the recovery of recyclable materials at the source or from commingled wastes at material separation facilities represents a good, and often profitable, practice.

5.3 Selection of Treatment Technologies

The alternative treatment methods need to be screened so as to select these, and/or their combinations, that are capable of fulfilling all legal and other management objectives. The selection can be assisted by the description of alternative technologies and the presentation of typical material and energy balances in Sect. 2.2 and by the citation of alternative management schemes and their combinations in Sect. 4.1.

The selected methods and their combinations can be pre-screened, using for this purpose the cost data given in Sect. 3.2, so as to select the most cost-effective alternatives.

5.4 Sitting of IWMFs

The graphical methodology presented in Sect. 3.1 can be followed for determining the number and the approximate location (within the selected overlay areas) of the IWMF sites required for each type of technology considered. This methodology is directly applicable in cases where the management schemes involve landfilling, as in Fig. 15a, or simple treatment with landfilling of inert residues. The same methodology can be also used in more complex management schemes, if properly applied. For example:

- In management schemes with incineration plants, which generate toxic residues requiring costly disposal, as in Fig. 15b, the search for the IWMF sites can be based on the waste incineration plants. The toxic waste disposal facilities, which are very few due to their strong economy of scale and the small quantities of residues involved, can be built in the sites with the largest incineration plants.
- In management schemes involving aerobic or anaerobic MBT plants producing RDF, along with RDF incineration plants generating toxic residues, as in Fig. 15c, the search for the IWMF sites can be based on the aerobic MBT plants. The SRF incineration plants, which are far fewer due to their strong economy of scale and the limited quantities of RDF involved, can be built in the sites of the largest aerobic MBT plants. The still fewer toxic waste disposal facilities can be built in the sites with the largest incineration plants.
- In management schemes involving biological drying plants producing SRF, along with SRF incineration plants generating toxic residues, as in Fig. 15d, the search for the IWMF sites cannot be based on the biological drying plants as these do not

offer any significant economy of scale (see Sect. 3.2.1). Clearly, the optimal location of these plants is as close to the waste generation sources as possible. In view of this, the search for IWMF sites can be conducted for the SRF incineration plants and the analysis can be based on the transportation of the SRF, which is about 55% of the quantity of the bio-dried MSW (see diagram of Fig. 7).

The definition of the approximate, but not the exact, location of IWMF sites from the above procedure is sufficient for the purposes of the present strategic plan formulation and comparative evaluation phase, as no transportation system design is involved and only approximate transportation cost estimates are required (see Sect. 5.6.2). For the same as above reasons, there is no need to define the transfer stations sites at this stage.

5.5 Formulation of Strategic Management Plans

The selection of alternative treatment technologies in Sect. 5.3 and the definition of the relevant sites for treatment and disposal installations in Sect. 5.4, specify the shape of the alternative management schemes to be considered. For each such scheme, planners can proceed to define the flow of wastes, products and residues around each type of installation (e.g. primary treatment, secondary treatment and/or final disposal), taking into consideration the following:

- The annual waste loads generated in the study area.
- The quantities of materials recovered at the source.
- The normalized material and energy balances for each type of installation, such as these given in Figs. 5, 6, 7 and 8 and in Table 1, but adapted to the waste composition in the study area and to the product yields emanating from the legal and other objectives that have to be fulfilled.

If a different management plan already exists, it can be defined in a similar way so as to be evaluated, along with the newly formulated ones.

5.6 Comparative Evaluation of Alternative Plans

The alternative plans, formulated according to Sect. 5.5 above, need to be evaluated in relation to their compatibility with the applicable legal and other management objectives, implementation cost, environmental friendliness and public acceptance characteristics.

5.6.1 Compatibility with Legal and Other Management Objectives

Each alternative management plan should be reviewed, with its material and energy balances checked, to ensure that all legal and other management requirements defined in Sect. 5.2 are fulfilled. Possible uncertainties, assumptions and deviations must be noted and further elaborated and plans with unresolved compatibility problems should be rejected.

5.6.2 Economic Performance

The economic performance of each alternative plan can now be analyzed. The objective of the analysis is the estimation of the capital investment, the annual operating costs, the annual revenues from products and incentives and, based on the above, the net annual cost of transportation, treatment and final disposal. This can be based on the data from the material and energy balances (see Sect. 5.5) and on the cost functions and information given in Sect. 3.2, which may have to be adapted to local conditions.

The estimates from the use graphs in Figs. 12 and 13 can be based on representative (e.g. average) plant sizes. For assessing the latter, the number of installation defined in Sect. 5.4 need to be considered.

5.6.3 Environmental Friendliness

On the local scale, the potential air, water and land pollution problems can be reviewed on the basis of information provided in Sect. 2.2 and in the literature. The existence of local infrastructure and enforcement mechanisms should be evaluated so as to ensure that proper management practices can be implemented and maintained, especially when toxic emissions, effluents and solid residues are involved.

On a global scale, the EU Directive 2008/98 has made mandatory the following hierarchy in waste prevention, management legislation and policy: (a) prevention; (b) preparing for re-use; (c) recycling; (d) other recovery; and (e) disposal. The above management priorities lead into the formulation of sustainable policies, with due consideration to environmental pollution and resource conservation issues. Each alternative plan can be classified in a hierarchy level according to the conditions specified by the Directive, and this provides a sound measure of its relative environmental friendliness on a global scale.

5.6.4 Social Acceptance

The administrations often blame people for reacting unfavorably to plans for building waste treatment and disposal installation in their neighborhood, but rarely admit that the strongest objections are often justified and can be effectively addressed though proper planning. In view of the above, alternative management plans need to be evaluated in terms of their social acceptance characteristics, taking into consideration parameters, such as the following:

- The suitability of sites selected for treatment and final disposal installations. As only the approximate location of sites is known at this stage, their suitability cannot be assessed. This however does not apply in the case of existing management plans and, in the case of new plans, for sites that may be known, right from the beginning, as particularly suitable (see Sect. 3.1).
- The environmental friendliness of the management scheme, as discussed in Sect. 5.6.3.
- The beneficial use of products. For example, the use of biostabilized organics for the restoration of disturbed lands.
- The minimization of road traffic problems through the use of transfer stations and especially rain transportation.
- The direct and indirect economic and other development possibilities offered to the local communities hosting IWMFs. Of major importance are the new jobs created by the waste management installations and services involved.

6 Development of Detailed Optimal Plans

The present section deals with the management of the MSW that remain after the application of material recovery at the source programs and considers the waste transportation (from the point where the packer vehicles complete their collection programs), treatment and final disposal.

The objective here is to describe a procedure for developing optimal plans that meet all legal and other management objectives with minimal cost (i.e. the sum of the annualized capital investment and annual operating cost of all transportation, treatment and disposal operations, taking into consideration the possible income from the sale of products and/or financial incentives).

The development of optimal plants is assisted by software systems, which are designed to fulfill some or all of the interacting planning requirements highlighted in Sect. 4.2. Ideally, a relevant software system should be able to:

- Consider all alternative treatment technologies of interest, with their specific products and yields, and define the best combination of technologies and the waste flow through them. The solution yields the optimal location and size of each pre-treatment, treatment and final disposal installation, along with their input sources and output receivers.
- Define in a similar way the optimal transportation system for the MSW, intermediate products and rejects. The system often comprises a network of transfer stations and may combine road, railroad and marine transport media.
- Consider all existing infrastructure and define its optimal use within the overall management plan.
- Develop optimal solutions subject to constraints, such as landfill holdup capacities, site-specific capacity limitations etc.

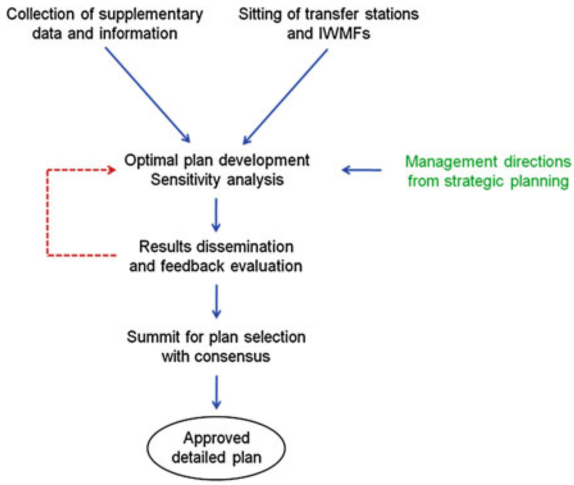


Fig. 17 Procedure for formulating detailed optimal plans

- Develop optimal dynamic plans in cases where some of the basic design parameters, such as the waste quantities and/or the management objectives, change significantly with time.
- Provide a comprehensive cost analysis for each optimal plan generated.

When an optimal solution is produced, the decision makers often wish to know the technical and economic impact of specific limitations reflecting the desires and objections of the local authorities (e.g. exclusion or imposition of a technology, exclusion or imposition of some sites, imposition of capacity limits etc.). To cope with this requirements, a series of optimal management plans can be developed, each of which meets a set of constraints. The comparison of these optimal plans at the municipal, prefectural and regional level constitutes the sensitivity analysis. The latter increases the planning efforts, but provides invaluable information to the decision makers, helping them to balance social and other preferences against costs and thus to select the most appropriate solution.

A rational procedure for the development and approval of optimal plants is illustrated in the diagram of Fig. 17.

According to this, planners need to define the exact location of the candidate sites, collect the necessary data and information and, on the basis of the management directions defined in the strategic planning phase, develop their detailed optimal plan and perform sensitivity analysis. The alternative plans, along with the associated cost data, are presented to the local authorities and the public and reviewed by relevant services (archaeological, forestry etc.). Depending on the feedback received, new plans may have to be developed so as to address more effectively public preferences and concerns and/or to comply with additional (e.g. land use) restrictions. A summit may then be convened with the objective of selecting one of the alternative plans presented, taking into consideration the relevant technical and economic data. The existence of alternative plans allows the participants to select the plan, not necessarily the least expensive one, which balances, in the best way, their preferences and objections against the associated costs. During this meeting, financial and other incentives can be negotiated until a decision is reached, hopefully with the concession of all parties involved.

The steps involved in the formulation of detailed optimal plans are described in more detail in the sections that follow.

6.1 Sitting of Installations

6.1.1 Sites for Transfer Stations

Sites for transfer stations are relatively easy to be located, even within congested urban areas, as the relevant nuisance problems are minor. In most cases, these sites are bordering highways, train terminal stations and/or ports, depending on the transport medium considered. The candidate sites should have a good geographic distribution and be easily accessible by the municipalities likely to be served. If possible, a somewhat excessive number of candidate sites is preferable, so as to allow the optimization program to select the most appropriate among them.

6.1.2 Sites for Treatment and Disposal Installations

The location of sites suitable for treatment and/or for disposal installations presents difficulties, especially for the latter, and requires considerable attention. Proper sites must meet a multitude of suitability criteria, depending on the kind of installation to be accommodated and must not create significant nuisance problems, Economopoulos [6]. More specifically:

The first step in the search of candidate sites is the definition of a carefully balanced set of suitability criteria. These must be strict enough for effective environmental protection, but not unduly strict so as to prevent the elimination of potentially suitable sites. Following this, the entire study area can be searched with GIS so as to locate the sites which meet all criteria. The GIS performs successive spatial operations using for this purpose spatial information relevant to the suitability criteria. The quality of the search results depends on the availability, completeness and accuracy of the relevant spatial information.

The second step involves field visits to the selected sites by a team of experts, so as to examine the site for apparent geological or other problems. Ideally, this step can be omitted if the available spatial information is complete, accurate and up-to-date, but this is rarely the case.

The third step involves the evaluation of the nuisance problems generated by each site. A key criterion is the visibility of the site from surrounding settlements, primary and secondary roads and archaeological sites. This task is aided by GIS, which can depict, in local maps, all areas with visibility to at least some part of the site under consideration. Additional criteria are the number, the size and the distance of the nearby settlements and the accessibility of the site through roads passing outside of the settlements. The morphology or the area needs also to be considered so as to detect potential problems, as for example conditions that affect adversely the dispersion of odors and emissions. GIS can provide significant input to all these evaluation tests.

Through the above procedure, the sites are screened so as to select the most suitable ones within or around the areas defined in Sect. 5.4. Unavailability of proper sites within or near these areas can be covered by sites in other locations that provide a reasonable overall spatial distribution. If additional sites turn out to be suitable, they can also be considered so as to allow the optimization program to select the most appropriate among them.

Generally, the total management cost of the resultant optimal plans is not very much dependent on the particular location of sites, as long as a sufficient number of candidate sites with good geographic coverage are available.

6.2 Collection of Data and Information

The kind and form of the input data required of optimal planning depend on the available computer system, its design and capabilities. For a computer system designed to perform the functions outlined in Sects. 4.2 and 6, input data, such as the following are required, Fig. 18:

- Quantities and composition of wastes. This information is normally collected at the strategic planning phase (see Sect. 5.1), but possible deficiencies in resolution, trends and general quality will have to be completed.
- Temporal distribution of the waste loads collected by the packer vehicles in each municipality. This is required for the design of the waste receiving and temporary storage units of transfer and treatment installations and can be expressed as maximum weekly loads, daily distribution of the weekly loads and hourly distribution of the daily loads.
- Location of existing installations, along with key data about their equipment, and performance characteristics. This information can be collected through specialized questionnaires for each type of installation.
- Location of candidate sites for the construction of transfer, treatment and final disposal installations, along with key characteristics (e.g. holding capacity of landfills) (see Sect. 6.1).
- Definition of alternative optimal routes that connect municipalities to sites and sites to sites, along with data about distances, mean velocities and mean transportation times. This information is normally produced through the use of GIS.

In addition to the above, information is required about the desirable sets of constraints related to the objections and/or preferences of the local communities so as to be used for the sensitivity analysis (see Sect. 6).

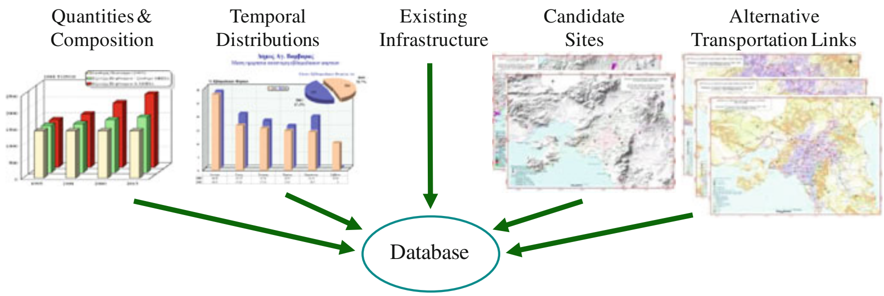


Fig. 18 Input data requirements by the plan optimization program

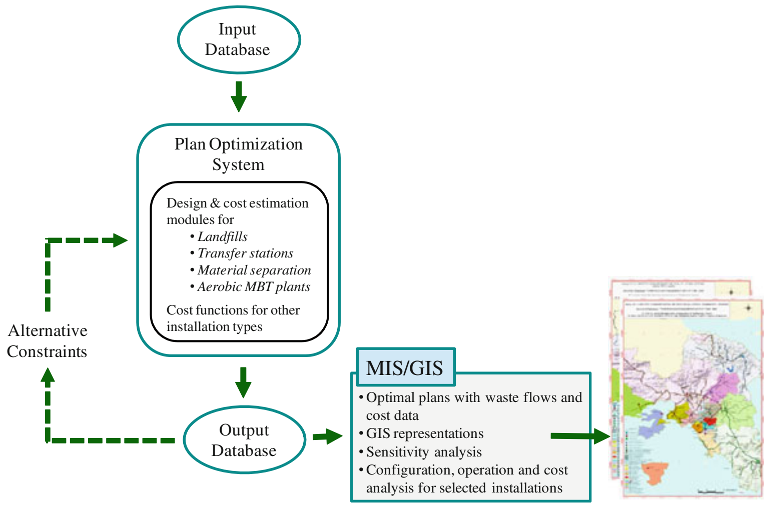


Fig. 19 Schematic flow chart of the plan optimization system illustrating selected eatures and functions

6.3 Development of Optimal Management Schemes

Depending on the sophistication of the available software some or all of the optimal planning aspects mentioned in Sects. 4.2 and 6 can be fulfilled. Most software tools can deal with the optimization of the waste transportation system, if everything else is specified.

The diagram of Fig. 19 illustrates some selected features and functions of a computer system designed to perform the tasks described in Sects. 4.2 and 6 and, in addition, to provide the optimal configuration and operation of selected types of installations, Economopoulos [5] and Economopoulou et al. [13].

This system comprises modules that estimate the capital investment and annual operating cost of each installation involved in the plan. The required cost data for transfer stations, material separation units, aerobic MBT plants and landfills are estimated analytically through the use of appropriate plant design and cost estimating modules, which are able to adapt the cost estimates to local conditions (temporal distribution of collected waste loads, waste composition etc.). The cost data for the remaining types of installations are generated through the use of cost functions, such as these given as in Sect. 3.1.

The output from the computer system is stored in a database, which feeds a Management Information System (MIS). The latter generates a number of reports, including reports with material flows and economic data that define the optimal solutions, reports that allow convenient comparison of the alternative plans at the Municipality, Regional and National level (sensitivity analysis), and reports with the indicative configuration, operation and cost analysis of selected installations (transfer stations, material separation units, aerobic MBT plants and landfills). Finally, GIS is used for the graphical representation of the optimal solutions, Economopoulos [5].

7 Discussion

The consecutive application of the two planning phases described in Sects. 5 and 6, enables planners to deal virtually with any management problem, irrespectively of its complexity. The strategic planning can be assisted, and the credibility of its results enhanced, by the use of software tools developed primarily for the detailed optimal planning phase. The application of the detailed optimal planning can be significantly simplified by the management options defined in the strategic planning phase. Nonetheless, the strategic and the detailed optimal planning constitute valuable management tools by themselves and can be applied independently, as for example in the following cases:

- If the resources are limited, planners could perform at least the strategic planning and, on the basis of its results, develop their detailed plan in the traditional way. The definition of the near optimal number and locations of sites, the screening of alternative treatment schemes and the formulation and comparative evaluation of alternative management plans of the strategic planning, contribute significantly towards the rationalization of the eventual plan.
- In not too complex studies, in which the alternative management options are not excessive, planners can proceed directly in the formulation of the detailed optimal plan, skipping the strategic planning phase.

The detailed optimal planning procedure is normally used for the formulation of integrated management plans, but it can be also used for optimizing some aspects of an existing plan, e.g. for optimizing the waste transportation system.

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