Development of an analytical computational tool for evaluating alternative plans for the management of urban waste

MSc Thesis

Panagiotidou Natalia

A.M: 2007019016, Email: npanagiwtidou@gmail.com

Thesis Committee:

G. Stavrakakis, Professor, Department of Electronic and Computer Engineering, Technical University of Crete (Supervisor)

K. Kalaitzakis, Professor, Department of Electronic and Computer Engineering, Technical University of Crete

E. Grigoroudis, Ass. Professor, Department of Production Engineering and Management, Technical University of Crete

DEPARTMENT OF ELECTRONIC AND COMPUTER ENGINEERING
TECHNICAL UNIVERSITY OF CRETE

Development of an analytical computational tool for evaluating alternative plans for the management of urban waste

Abstract

One of the main objectives of Municipal Waste Planning and Management in Europe is to integrate the environmental impacts into the process of developing or revising waste management plans, taking into account economic and technological availability constraints. The complex interplay between these conflicting objectives hinders the determination of an optimal Municipal Solid Waste management scheme for municipalities and other competent authorities. The tool was developed for the purpose of supporting the involved actors in waste management planning in Balkan countries under a set of social, technical, environmental, economical and legislative constraints and thus, determining the most effective waste management system for the target area. Most of the Balkan regions lack experience, data availability and infrastructure due to the absence of a waste management strategic and/or monitoring plan. Thus, it was important to be able to overcome these constraints by incorporating default—country specific values, identified through bibliography and the experience of waste management plans in various Balkan regions. The present work describes the structure of the tool and presents the results from the applications of the tool for the region of Attiki and the island of Crete, Greece.

Ανάπτυξη αναλυτικού υπολογιστικού εργαλείου για την αξιολόγηση εναλλακτικών σχεδίων διαχείρισης αστικών απορριμάτων

Περίληψη

Ένας από τους κύριους στόχους της Ολοκληρωμένης Διαχείρισης Στερεών Απορριμάτων στην Ευρώπη είναι η ενσωμάτωση των περιβαλλοντικών επιπτώσεων στη διαδικασία κατάρτισης ή αναθεώρησης των σχεδίων διαχείρισης αποβλήτων, λαμβάνοντας υπόψη τους οικονομικούς και τεχνολογικούς περιορισμούς. Η πολύπλοκη αλληλεπίδραση μεταξύ αυτών των αντικρουόμενων στόχων εμποδίζει τον προσδιορισμό του βέλτιστου σεναρίου διαχείρισης αποβλήτων για τους δήμους και τις λοιπές αρμόδιες αρχές.

Το γραφικό περιβάλλον με το ενσωματωμένο Σύστημα Υποστήριξης Αποφάσεων (ΣΥΑ) που παρουσιάζεται στην παρούσα εργασία, αναπτύχθηκε για την υποστήριξη λήψης αποφάσεων των εμπλεκόμενων φορέων στη διαχείριση των αποβλήτων στις Βαλκανικές χώρες δεδομένου ενός συνόλου κοινωνικών, τεχνικών, περιβαλλοντικών, οικονομικών και νομοθετικών περιορισμών και ως εκ τούτου, τον προσδιορισμό του πλέον αποτελεσματικού συστήματος διαχείρισης αποβλήτων για την εξεταζόμενη περιοχή.

Σε αυτή την κατεύθυνση, ένα από τα μεγαλύτερα εμπόδια είναι ότι οι περισσότερες από τις Βαλκανικές χώρες δεν έχουν την εμπειρία, τη διαθεσιμότητα των δεδομένων και την υποδομή λόγω της έλλειψης νομοθετικού πλαισίου και εναιαίου σχεδίου δράσης. Έτσι, ήταν σημαντικό η συγκεκριμένη εφαρμογή να είναι σε θέση να ξεπεράσει αυτούς τους περιορισμούς με την ενσωμάτωση προεπιλεγμένων δεδομένων εισόδου ανάλογα με τη χώρα επιλογής, δεδομένα τα οποία προσδιορίστηκαν με βάση την βιβλιογραφία και την εμπειρία στα θέματα διαχείρισης των αποβλήτων σε διάφορες περιοχές των Βαλκανίων. Η παρούσα εργασία περιγράφει τη δομή του γραφικού περιβάλλοντος του ΣΥΑ και παρουσιάζει τα αποτελέσματα της εφαρμογής της πολυκριτήριας μεθόδου PROMETHEE II στην Ελλάδα, και συγκεκριμένα στις περιοχές της Αττικής και της Κρήτης.

Acknowledgements

The research work presented here was carried out under the support of LIFE+ BALKWASTE project–Waste Network for sustainable solid waste management planning and promotion of integrated decision tools in the Balkan Region (LIFE+ 07/ENV/RO/000686). The project deiverables, as well as the DSS tool executable and manual can be found in the project website (**http://www.balkwaste.eu/**)

I would like to express my deepest gratitude to my advisor G. Stavrakakis for his excellent guidance, for caring even on personal level, for his patience and his support through the demadning review process of LIFE+ BALKWASTE PROJECT.

A big thank you goes to my husband, who has always been my pillar, my joy and my guiding light. He was always there to support me technically, emotionally and morally during my postgraduate years and this thesis would certainly not have finished without him.

Finally, my family and all the people who believed in me from my first years in Greece; they were a constant source of encouragement and support during my studies in Crete.

Contents

Chapter 1

Introduction

The most important objective of EU waste management policies is based on the need to divert the major part of Municipal Solid Waste (MSW) from landfills. In the case of Balkan countries, where there is still the problem with open burning of scattered waste and uncontrolled dumpsites, the need for immediate action is becoming of utmost importance Guerrero et al. [2013]. The particular computer integrated tool aims at supporting the decision maker in Balkan countries throughout the various steps of waste management planning and allows a thorough understanding of the complex interplay between the numerous factors involved in integrated and sustainable waste management. Most of the existing models and accounting tools, which were developed for assessing waste management practices, focus on cost or environmental analysis, incorporating a large number of variables, thus resulting in high-complexity solutions, inadequate for practical use Bani et al. [2009]. Many applications avoid these constraints by using Geographic Information System (GIS) to help the planner to understand the spatial nature of the waste management system and its relation with social and environmental impacts Chang and Wang [1996]; Haastrup et al. [1998]; MacDonald [1996]; Repoussis et al. [2009].

The DSS tool presented here, comprises of more than one tools, integrated into an interactive user-friendly graphical interface in a way that allows the user to fully participate in the waste management planning Panagiotidou et al. [2012a,b]; Stavrakakis et al. [2010]:

- an automated process tool, identifying and suggesting the most suitable technologies within an integrated waste management framework, and guiding the decision-maker towards formulating appropriate scenarios for waste management planning
- an analytical tool, evaluating available waste management options through Material Flow Analysis, providing a multidisciplinary comparison (Environmental, Economic, Social, Legislative and Technical) between different waste management technologies
- a decision support system, assisting the appropriate authorities on selecting the optimal waste management strategy, through comparative assessment of alternative waste manage-

ment scenarios, based on a predefined set of quantitative and qualitative criteria

Since this process cannot be fully automated, minimum feedback from the decision-maker is required, in the form of providing suggested values/data for the target country or area, as well as guidelines for waste management planning, defining the ratings per technology for each of the qualitative criteria and determining the weight of each criterion used for the assessment of alternative waste management scenarios. By this way, user is provided with the ability to include social viewpoint for various waste management technologies, which is a significant factor affecting the decision making process.

Chapter 2

The basic concept of a waste management planning into DSS tool

Waste management plans have a key role to play in achieving sustainable waste management. Their main purpose is to give an outline of waste streams and treatment options. More specifically they aim to provide a planning framework for the following:

- Compliance with waste policy and target achievement: Waste management plans, national as well as local/regional are important instruments contributing to implementation and achievement of policies and targets set up in the field of waste management at the national and the European Union level
- Outline of waste characteristics and sufficient capacity for managing waste: Waste management plans give an outline of waste streams and quantities to be managed. Furthermore, they contribute to ensuring that the capacity and the nature of collection and treatment systems are in line with the waste to be managed
- Control of technological measures: An outline of waste ensures identification of areas in which technological measures should be taken to eliminate or minimize certain types of waste
- Outline of economy and investment requirements: Waste management plans make way for a statement of financial requirements for the operation of collection schemes, treatment of waste etc. On this basis, the needs for future investments in waste treatment plans may be determined.

There are several ways to develop a waste management plan and different methodologies can be always applied depending on the objective of the plan and on the available information. European Regions that developed waste management plans and constructed the appropriate infrastructure twenty years ago have a certain experience on running waste management and monitoring systems. As a result the current waste management status can be described in detail with accurate input on waste quantities, waste composition, technology costs and impact, absorption of secondary products from the regional and local recyclable market etc. This makes the development of future plans in terms of data availability and experience easier. The methodology that will be described in the next chapters is based on the experience in developing waste management plans in various Balkan Regions that lack infrastructure and due to the absence of a monitoring system cannot provide any significant input. The particular study has to be based mainly on assumptions, literature review and the few existing data.

2.1 Definition of the current status

After defining the main objectives and targets of the plan the next step is to define the target area and to describe as clearly as possible the existing situation in the waste management field.

2.1.1 Estimation of the Waste Quantities

Regardless if a local or regional waste management plan is being developed the estimation of the waste quantities is equally important and should begin immediately after the relevant waste streams have been identified e.g. MSW in this case. Municipal Waste generation can be estimated either directly from existing data in the defined area or by using demographic data. In the Balkan Region many areas lack such facilities and the waste quantities usually have to be estimated. In that case, the usual methodology is the following:

- Estimate the average generation rate per capita. National waste management plans usually contain an average generation rate per capita. Depending on the country this value may significantly vary and is usually linked to the GDP. Another option is to use generation rates of neighboring regions that have conducted waste analysis studies and have calculated the local generation rate or use EUROSTAT data. According to Eurostat News Release 37/2011 (8 March 2011) on Recycling accounted for a quarter of total municipal waste treated in 2009, the generation rate for the examined countries for 2009 is shown in Table 2.1.1.

- Estimate the total waste quantities of the examined area by multiplying the average generation rate per inhabitant with the population of the area.

The most usual methodology for estimation of future trends on waste generation is to estimate the population growth rate during the past years and to make future projections. Thus, the DSS tool performs projection of waste generation growth with starting year 1995 until the last year of planning period, which must be at least a timeframe of 20 years for legislative and economical reasons. In order to perform the projection for waste generation, the following data should be defined first: (see Figure 2.1):

- Name of the country. Choosing from the pop-up menu one of the five Balkan countries activates the suggested values for the specific country, corresponding to EU average values.
- Equivalent population. If there are no data for the equivalent population, data from the latest census should be used.
- Population reference year. It is considered the latest census year and cannot be earlier than 1995, in order to use more valid and accurate data for the simulation.
- Planning period. Must be between 20 and 30 years.
- Waste generation per capita (kg/day/inhabitant) at population reference year. In case census data are used, waste generation per inhabitant should correspond to the latest census year, otherwise, country-specific recommended values can be used.
- Annual waste growth rate (%). Indicates the annual increase in waste generation — the average growth rate of 1.5% for Balkan countries is suggested.

Table 2.1: Municipal solid waste generation

Region	**Municipal waste generated (kg per person)**
EU27	513
Bulgaria	468
Greece	478
Romania	396
Slovenia	449

Moreover, the properties of the last year of planning by DSS tool are based on the current year and the planning period defined (prediction time period). For the purpose of predicting the waste generation growth for the time period, DSS tool initially evaluates the population projection using a linear growth model (see Eq.2.1,2.2) with initial year 1995. The purpose of using the particular year is that the targets, which have been set by Landfill Directive, described in the the following section, are based on amounts produced on the year 1995.

$$\Delta P/\Delta t = (P_b - P_o)/(t_b - t_o) = K_1; \tag{2.1}$$

where ΔP is the change in population; Δt is the time change; P_b is a starting point of the projection; P_o is the initial population (in the applicable linear growth period), t_b is the base year (start of projection); t_o is the initial year (earliest year in the applicable linear growth period); and K_1 is the growth rate. The resulting projection, assuming linear growth, is calculated using the formula:

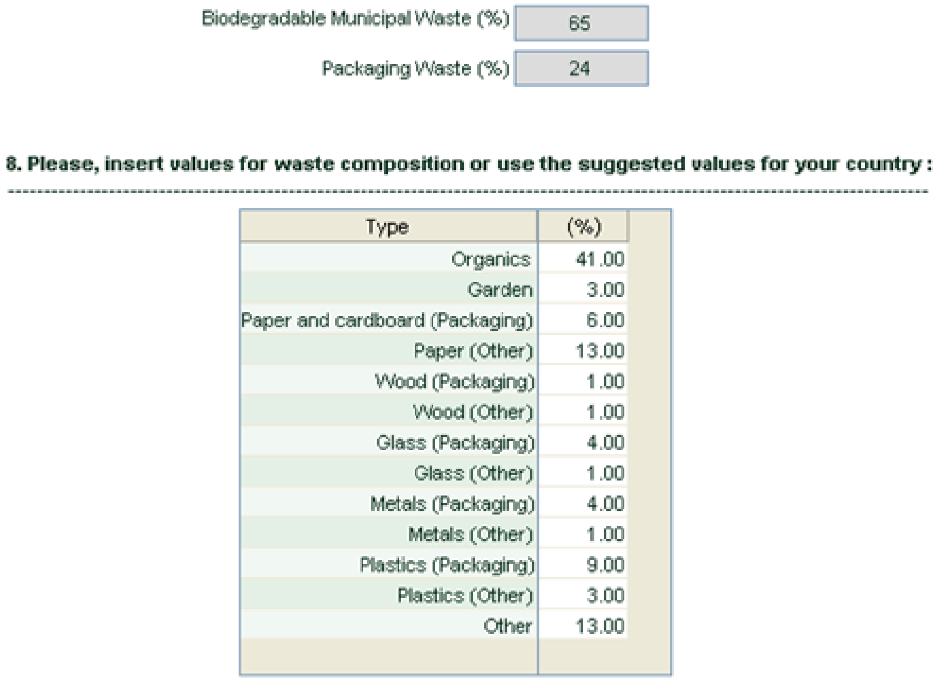
$$P_f = P_b + K_{1t}; \tag{2.2}$$

where P_f is the future population; $t = t_f - t_b$ is the number of years projected into the future; and t_f is the future year (end of projection).

Figure 2.1: Example of input data, defining the characteristics of waste generation

2.1.2 Waste Composition

After the waste quantities have been determined the next step is to determine the composition of the Municipal Solid Waste. For the purpose of the particular study, the results from two sampling analysis studies, which took place in the case study areas of Bulgaria and Romania are considered. Waste samples were analysed in respect to their composition and other characteristics. The results for the six counties of North-East Region in Romania and the Region of Razlog in Bulgaria on MSW Composition are summarized in Table 2.1.2.



Type	(%)
Organics	41.00
Garden	3.00
Paper and cardboard (Packaging)	6.00
Paper (Other)	13.00
Wood (Packaging)	1.00
Wood (Other)	1.00
Glass (Packaging)	4.00
Glass (Other)	1.00
Metals (Packaging)	4.00
Metals (Other)	1.00
Plastics (Packaging)	9.00
Plastics (Other)	3.00
Other	13.00

Figure 2.2: Example of input data for definition of characteristics of waste generation

Table 2.2: Waste Composition

	BULGARIA		ROMANIA	
Fractions	**1st Sorting**	**2nd Sorting**	**1st Sorting**	**2nd Sorting**
Plastic	9,2%	10,6%	12,50%	12,60%
Paper	7,3%	6,2%	11,10%	13,70%
Metals	0,8%	0,7%	1,10%	1,60%
Glass	4,4%	2,8%	3,50%	4,60%
Textile	2,7%	3,1%	3,00%	2,10%
Wood	1,6%	1,5%	0,80%	0,40%
WEEE	0%	0%	0,20%	0%
C&D	15,8%	13,6%	8,60%	0,70%
Organic (rest)	58,3%	61,6%	59,20%	64,40%
TOTAL	100%	100%	100%	100%

The DSS tool based on the studies for waste composition in Balkan countries provides an average waste composition, corresponding to the country selected. The types of provided waste, with the exceptions of “Organics” and “Garden” waste, are divided into two subcategories:

"Packaging" and "Other" waste (see Figure 2.2), since a clearly correlation between waste composition and Packaging Waste Directive is needed.

The following waste characteristics are evaluated by DSS tool, according to the waste composition defined:

- Biodegradable Municipal Waste (%), which consist mainly of organics and paper and their diversion from landfills is regulated through the Landfill Directive 1999/31/EC

- Packaging (%), which consist mainly of plastic, paper, glass, metal and wood material and are used for packaging purposes, such as containment, protection, handling, delivery and presentation of goods.

The particular values are important for waste management planning, as they are strongly connected with Packaging and Landfill Directives.

2.2 Legislative requirements

The first step in the development of a WM Plan is to define the projects overall objectives. Those objectives derive from European and national waste management policy. Concerning the Balkan Region it has to be outlined that in most of the cases the national policies are usually a result of the transposition of EU waste related Directives and initiatives to set objectives past the targets set by the EU are not very common.

2.2.1 Landfill Directive

Landfill Directive corresponds to 1999/31/EC Directive with the following obligations:

1. Set up a national strategy for the implementation of the reduction of biodegradable waste going to landfills in a specific interval of time, by means of recycling, composting, biogas production or materials/energy recovery, and notify the Commission of this strategy.

2. Ensure that this strategy fulfills the following targets:

    - In 2006, BMW going to landfills must be reduced to 75% of the total amount of BMW produced in 1995, for which standardized Eurostat data are available:
    - In 2009, BMW going to landfills must be reduced to 50% of the total amount of BMW produced in 1995 for which standardized Eurostat data are available;
    - In 2016, BMW going to landfills must be reduced to 35% of the total amount of BMW produced in 1995 for which standardized Eurostat data are available.

However, countries such as Greece and United Kingdom, where more than 80% of the waste end up at landfills in the reference year, gain a 4-year extension to reach the aforementioned targets. The above mentioned countries are formulating their strategies by placing targets for the years 2010, 2013 and 2020. Concerning these targets, a table for the "Landfill Directive" obligations is provided by the DSS tool, presents the amount of BMW going to landfill, the amount of BMW to be diverted, and the amount of MSW to be diverted, for the years 2010, 2013 and 2020. It should be stressed that, the calculation of particular amounts of waste is based on the amounts of MSW and Biowaste produced in 1995 according to the projection of waste generation performed by the DSS tool with starting year 1995 until the last year of planning period.

TOTAL WASTE FOR TREATMENT (tn) : 448,800 tn

LANDFILL DIRECTIVE

	BMW to landfill (tn)	BMW to be diverted (t...	MSW to be diverted (tn)
2010	158,075	87,164	144,193
2013	105,384	147,400	243,837
2020	73,768	197,531	326,768

Figure 2.3: Example of waste to be diverted according to Landfill Directive

2.2.2 Packaging Directive

Packaging Directive refers to 94/62/EC Directive 94/62/EC as amended by Regulation 1882/2003, Directive 2004/12/EC and Directive 2005/20/EC concerning of packaging waste, focuses on the promotion by MS of the use of packaging system. Thus, necessary measures must be taken, to attain the following quantified targets covering the whole of their territory:

- At least 60% by weight of all packaging waste must be recycled.
- At least 60% by weight for glass must be recycled.
- At least 60% by weight for paper and cardboard must be recycled.
- At least 50% by weight for metal must be recycled.
- At least 22.5% by weight for plastics must be recycled.
- At least 15% by weight for wood must be recycled.

The aforementioned targets are summarized in "PACKAGING DIRECTIVE" table in DSS tool. The particular table (see Figure 2.4) presents the compliance of values inserted for recycling via diversion (%) per waste stream in "WASTE FRAMEWORK DIRECTIVE" table (see the next chapter) with the obligations of "PACKAGING DIRECTIVE".

PACKAGING DIRECTIVE

Material	(%)	(tn)
Paper	60	13,437
Glass	80	18,167
Metal	50	8,886
Plastic	60	31,775
Wood	60	1,104

% TOTAL RECYCLING FOR PACKAGING MUST BE AT LEAST 60%

62.35

Figure 2.4: DSStool Table for Packaging Directive per waste stream (% and tn)

2.2.3 Wasteframework Directive

Waste Framework Directive refers to 2008/98/EC and encourages the Member States to take the necessary measures designed to achieve the following targets:

- By 2020, the preparing for reuse and recycling of waste materials, such as at least paper, metal, plastic and glass from households and possibly from other origins — as far as these waste streams are similar to waste from households —, shall be increased to a minimum of overall 50% by weight.

- By 2020, the preparing for reuse, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 17 05 04 in the list of waste shall be increased to a minimum of 70% by weight.

In order for the aforementioned restrictions to be fulfilled, values in the "WASTE FRAMEWORK DIRECTIVE" table provided by DSS tool must comply with the aforementioned restrictions for recycling via diversion for packaging waste according to Packaging Directive. The DSS tool, using data inserted for packaging waste in the "WASTE FRAMEWORK DIRECTIVE" table, calculates the "TOTAL RECYCLING FOR PACKAGING", which must be at least 60%. If this target is not achieved (see Figure 2.6), an error message suggests to increase the recycling via diversion (%) for packaging waste.

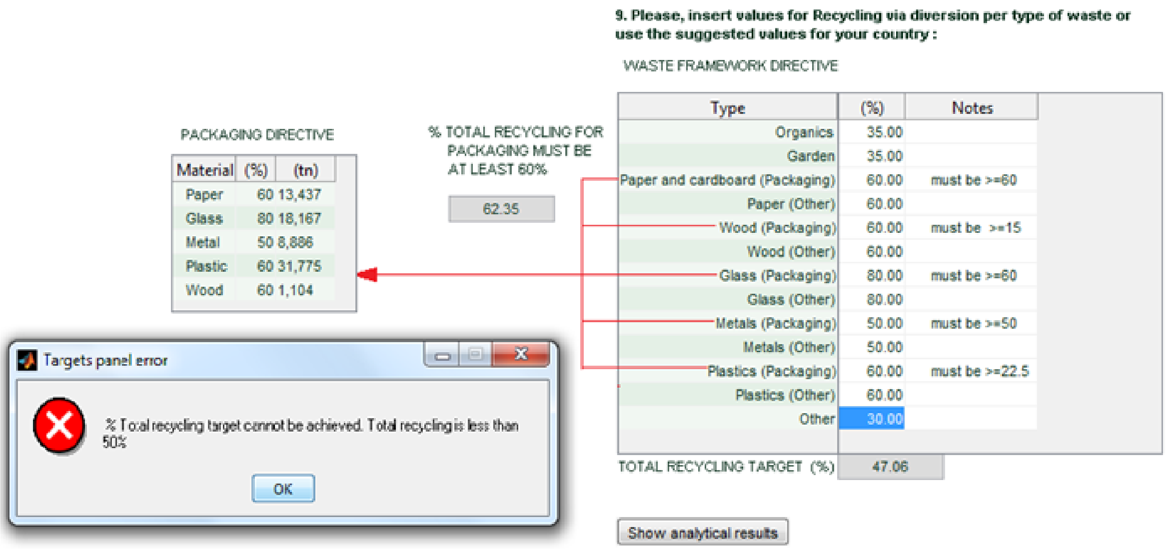


Figure 2.5: Example of recycling via diversion according to the Packaging Directive and error message box for low Total recycling Target

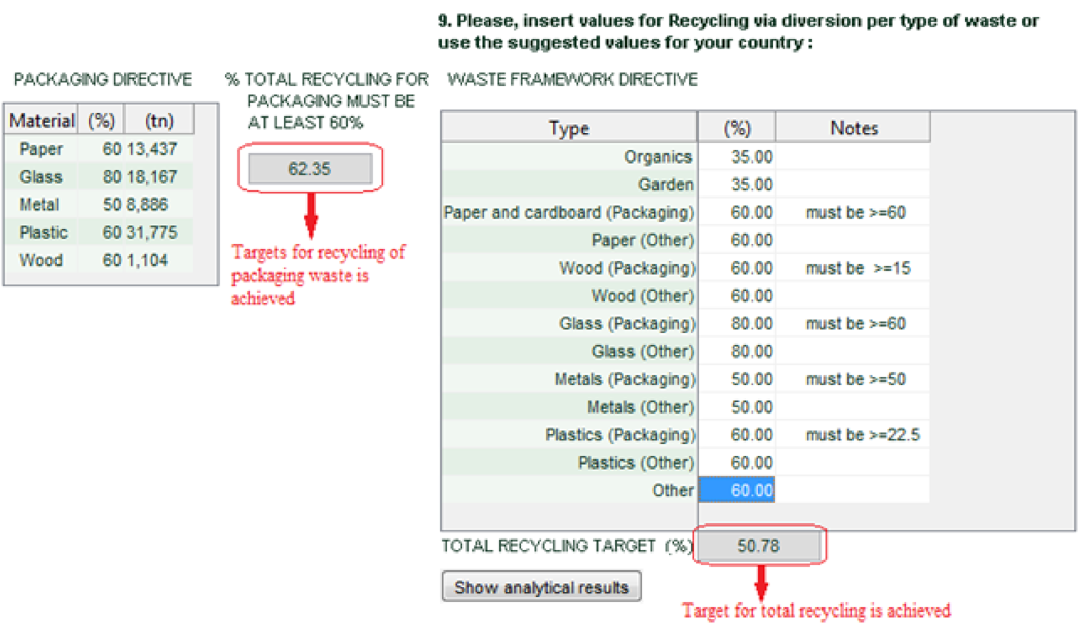


Figure 2.6: Targets for packaging waste and total recycling are achieved (Case study of Crete))

Moreover, the values for recycling via diversion (%) for “Food and Garden”, “Packaging” and “Other” waste streams are used for the evaluation of “TOTAL RECYCLING TARGET”, which must be at least 50%. If this target is not achieved, an error message suggests to increase the recycling via diversion (%) for “Food and Garden”, “Packaging” and “Other” waste streams through the “WASTE FRAMEWORK DIRECTIVE” table (see Figure 2.5).

In case that all targets for recycling are achieved, the ability to inspect analytical results for projection of MSW generation from year 1995 to the last year of planning, and for the following waste streams, important for waste management planning is provided:

- “Source separated Packaging” waste (tn)
- “Source separated Biowaste for biological treatment” (tn)
- “Waste other than Packaging” to be treated from industries (e.g. printed paper) (tn)
- “Mixed residues to treatment” (tn)

It is important to mention that, for the purpose of waste management planning, all the waste streams are used, except for “Waste other than Packaging” (see Figure 2.7), which consists of non-separated at source waste from “Other” waste stream.

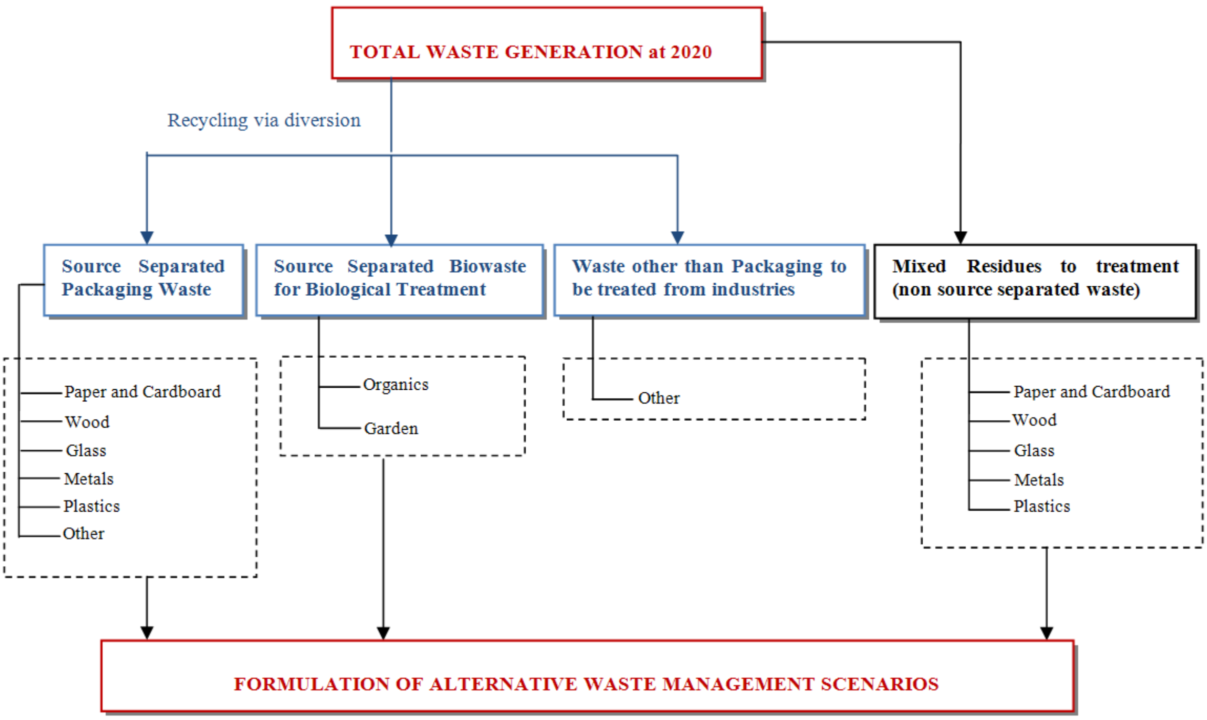


Figure 2.7: Flow diagram for Total Waste Generation

As it is shown in Figure 2.7, packaging waste, Biowaste and residual waste (mixed residues to treatment) are used for formulation of alternative scenarios for the purpose of waste management planning.

2.3 Existing Infrastructure

Defining existing waste management infrastructures in the examined area is also an important element for the development of an integrated plan. Existing structures that must be taken into account include:

- Collection of mixed MSW and separation at source schemes
- Material recovery facilities
- Waste Treatment plants (MBT plants, Incineration plants, composting, etc.)
- Waste Disposal areas (sanitary landfills, uncontrolled landfills)

Technology Index	Technology Description	Biowaste	Packaging waste	Residual waste	Minimum viable capacity
Tech.1	Composting	✓			
Tech.2	Anaerobic digestion (AD)	✓			>5000 tn
Tech.3	Material Recovery Facility (MRF)		✓		
Tech.4	Aerobic Mechanical and Biological Treatment (MBT)-Composting-Recyclables			✓	
Tech.5	Aerobic Mechanical and Biological Treatment (MBT)-Composting-RDF			✓	
Tech.6	Anaerobic Mechanical and Biological Treatment (MBT)-AD-Recyclables			✓	>12500 tn
Tech.7	Anaerobic Mechanical and Biological Treatment (MBT)-AD-RDF			✓	>12500 tn
Tech.8	Biodrying			✓	
Tech.9	Incineration			✓	>50000 tn

Table 2.3: Description of technologies

Furthermore, quantities of MSW treated by the above existing waste managemnt facilties should be defined and the assessment of the existing infrastructure will initiate with the mapping of waste treatment technologies as for their processing potential, operational parameters and the respective technical specifications should be defined. The rest of the respective quantities can be treated by the infrastructure that will be proposed during the formation of alternative scenarios. Thus, the quantities of MSW that will exceed the capacity and/or processing potential of the existing infrastructure will be the critical parameter for the overall dimensioning of the facilities to be constructed as part of the strategic plan. These facilities will include technologies that may be similar to those of the current situation of the target area. However, the processing potential of the required infrastructure will be based on alternative waste management technologies that are maximizing the utilization of all MSW fractions towards recycling and energy recovery.

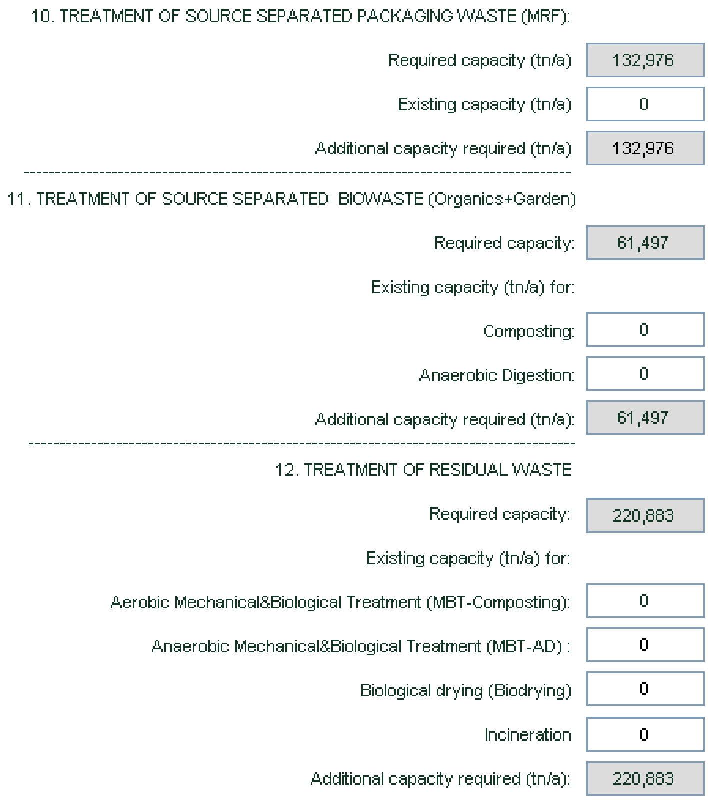


Figure 2.8: Example of input data in Waste management facilities panel

The integration of this part of waste management planning in the DSS tool is based on the definition of following capacities of waste management facilities for Packaging Waste, Biowaste and Residual waste (see Figure 2.8):

- Required Capacity (tn/a), calculated considering the previous data for the waste characteristics and legislative targets
- Existing Capacity (tn/a), if exists, should be defined by user for each technology.
- Additional Capacity required (tn/a), calculated by DSS tool and consists the baseline for formulation of alternative waste management scenarios. Moreover, in order to proceed

with formulation of alternative scenarios, the validation process "CHECK FOR CAPACITY" is implemented for all facilities except for MRF, as there is no restriction on capacity ((capacity >0 tn)), to provide information concerning the viability of each facility.

More particularly, additional capacity for further treatment is calculated and "CHECK FOR CAPACITY" module is initiated using the restrictions described in Table 2.3 (see Figures 2.9,2.10).

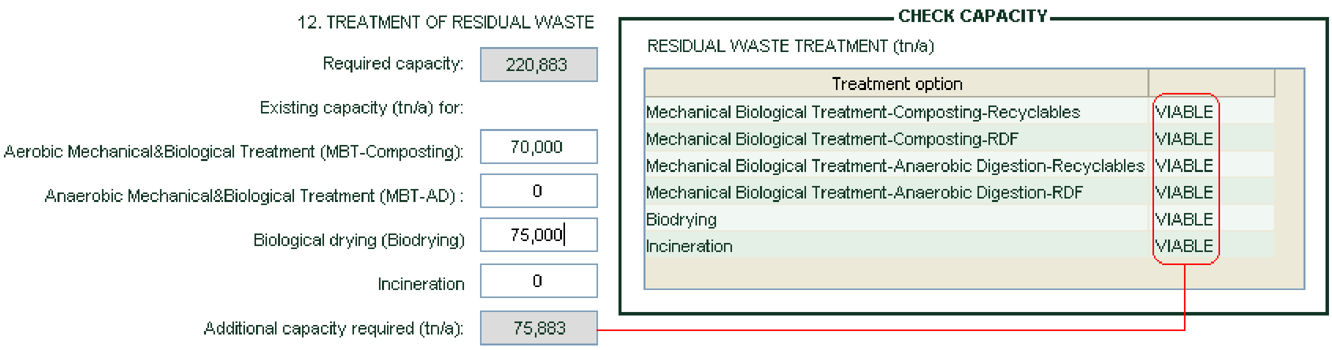


Figure 2.9: Example for input data in existing capacity for Residual waste treatment — all treatment options are viable (Case study of Crete)

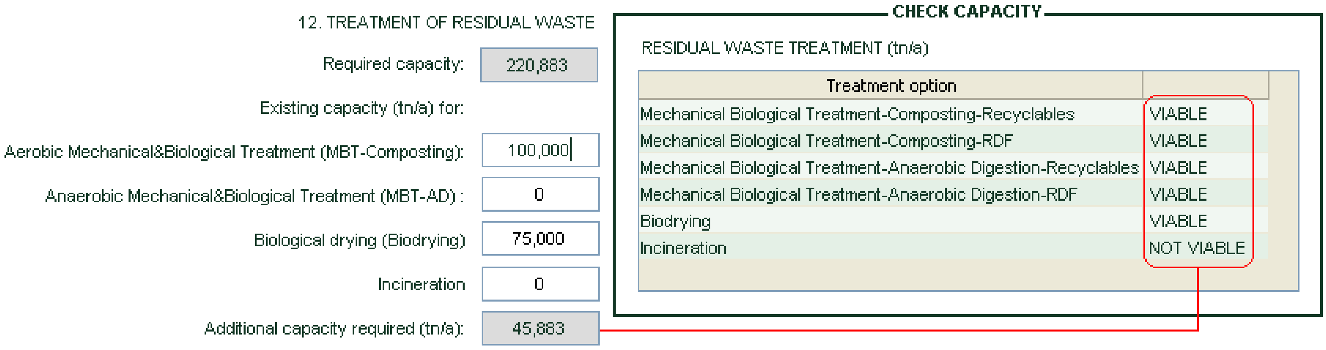


Figure 2.10: Example for input data in existing capacity for Residual waste treatment — Incineration is not viable

Chapter 3

Multi-criteria decision analysis in waste management planning

Multi-Criteria Decision Analysis (MCDA), or Multi Criteria Decision Making (MCDM), is a discipline aimed at supporting decision makers who are faced with making numerous and conflicting evaluations. MCDA aims at highlighting these conflicts and deriving a way to come to a compromise in a transparent process. MCDA methods have been developed to improve the quality of decisions involving multiple criteria by making choices more explicit, rational and efficient. The goal is to create a structured process to identify objectives, create alternatives and compare them from different perspectives.

The MCDM methods could be divided into category of Outranking relations, Ordinal regression and Multi-attribute Utility and Values Theories (MAUT, MAVT) according to the type of MCDM theory. Also, the MCDM methods can be classified according to the type of the data they use (deterministic, stochastic, or fuzzy MCDM methods) or according to the number of decision makers involved in the decision process (single decision maker MCDM methods and group decision making MCDM). The methods which belong to each of the above classes share common characteristics of conflict among criteria, incomparable units, and difficulties in selection of alternatives.

For the application of any MCDM method the following steps shall be applied:

- Define the scope and main objective of the Multi Criteria Analysis and identify the decision makers
- Selecting the most suitable MCDM method
- Formulate and define the scope of the options to be evaluated
- Identify criteria for evaluating the performance of each option
- Weighting of the criteria so as to reflect their relative importance to the decision

- Scoring the criteria, so as to assess the expected performance of each option against the criteria.
- Application of MCDM model with ranking of the alterative options.

Figure 3.1: Benefits of MCDA in waste management planning

As presented in the Figure 3.1, the advantages of MCDA can be summarized below:

- MCDA directly involves the stakeholders facing a particular decision problem in order to detect their preferences and values regarding the decision criteria. Hence, the extracted values better reflect concerns and priorities of the people directly affected Diakoulaki [2003].
- MCDA is a multi-disciplinary approach amenable to capturing the complexity of natural systems, the plurality of values associated with environmental goods and varying perceptions of sustainable development. The stakeholders participating in a MCDA procedure have the possibility and the responsibility to take into account perspectives and information that may go beyond those considered in their own discipline Diakoulaki [2003].
- MCDA applications can consider a large variety of criteria, whether quantitative or qualitative, independent of the measurement scale. Hence, it allows for a more comprehensive

analysis for sustainability, since it can include all aspects of sustainability rather than being restricted to marketed goods or monetized costs and benefits Diakoulaki [2003].

- MCDA supports transparent decision making procedures, as individual preference is reflected through the assignment of criteria weighting values. Hence, decision-makers cannot interfere in any other evaluation process, as long as the scoring of the criteria has been made on real values and not subjective ones.

For the aforementioned reasons the Multi-criteria Decision Analysis methods (MCDA) have been used in a number of academic studies and researches in the field of waste management and environmental issues with growing number of applications. The most of them are mainly referring to location of waste treatment and disposal plants (Briggs et al. [1990]; Haastrup et al. [1998], assessment and selection of the most appropriate waste management system in term of environmental requirements for prevention, collection, recovery treatment, disposal to landfill and social aspects apart from common cost analysis. (Hanan et al. [2012]; Hokkanen and Salminen [1997]; Kapepula et al. [2007]; Roussat et al. [2009]).

Also, recently many DSS applications integrate Geographical Information Systems (GIS) for dealling more effectively with the spacial problem of waste disposal and treatment plants Chang et al. [2008]; de Oliveira Simonetto and Borenstein [2007]; Gómez-Delgado and Tarantola [2006].

3.1 The PROMETHEE I and II methods

This method uses the outranking principle to rank the alternatives, combined with the ease of use and decreased complexity. It performs a pair-wise comparison of alternatives in order to rank them with respect to a number of criteria. The basic data of a multicriteria problem consist of an evaluation table resulting from a performance score $g_j(a)$ of each alternative action a for each criterion j. The preference structure of PROMETHEE methods is based on pairwise comparisons, in which the deviation $d_j(a,b)$ between the evaluations of two alternatives a,b on a particular criterion j is considered Figueira et al. [2005]:

$$d_j(a,b) = g_j(a) - g_j(b). \tag{3.1}$$

Also, there are six generalized criteria functions for reference namely, usual criterion, quasi criterion, criterion with linear preference, level criterion, criterion with linear preference and indifference area, and Gaussian criterion. The method uses preference function $P_j(a,b)$ in which the deviation $d_j(a,b)$ between two alternatives a,b is evaluated Figueira et al. [2005]:

$$P_j(a,b) = F_j\left[(d_j(a,b)\right]. \tag{3.2}$$

The selection of the preference function for each criterion and corresponding preference p_j and indifference thresholds q_j depends on the dispersion of the performance values of the scenarios for the particular criterion and the nature of the criterion. More particularly, the q indifference threshold is the largest deviation which is considered as negligible by decision maker, while the p strict preference threshold is the smallest deviation which is considered as sufficient to generate a full preference.

Indifference and preference thresholds can be empirically estimated as percentages on the maximum deviation $max\left[d_j(a,b)\right]$ between the evaluations of two alternatives on a particular criterion. Often, the percentage of the deviation, which can be used to set the indifference and preference thresholds varies from 5% to 15% and from 10% to 30% respectively.

As soon as the evaluation table $\{g_j(\cdot)\}$ is given, and the weights w_j and the preference function $P_j(a,b)$ are defined, the PROMETHEE procedure can be applied. First, aggregated preference indices are evaluated by the equation Figueira et al. [2005]:

$$\begin{cases} \pi(a,b) = \sum\limits_{j=1}^{k} P_j(a,b)w_j \\ \pi(b,a) = \sum\limits_{j=1}^{k} P_j(b,a)w_j; \end{cases} \tag{3.3}$$

where $\pi(a,b)$ is expressing with which degree a is preferred to b over all the criteria $\{1,2,...,k\}$; and $\pi(b,a)$ how b is preferred to a.

Outranking flows

The ranking of alternatives is based on calculation of Positive $\phi^+(a)$ and Negative $\phi^-(a)$ outranking flows Figueira et al. [2005]:

$$\begin{aligned} \phi^+(a) &= \tfrac{1}{n-1} \sum_{x\in A} \pi(a,x) \\ \phi^-(a) &= \tfrac{1}{n-1} \sum_{x\in A} \pi(x,a) \end{aligned} \tag{3.4}$$

where A is a finite set of defined alternatives $\{a_1,a_2,...,a_i,a_n\}$; and $(n-1)$ is the set of alternatives which are compared with each alternative $a \in A$.

The PROMETHEE I partial ranking (P^I, I^I, R^i) is obtained from the intersection of positive and negative flows for each pair of alternatives $a,b \in A$ Figueira et al. [2005] :

- Preference

$$aP^Ib, \quad if \begin{cases} \phi^+(a) > \phi^+(b) & and & \phi^-(a) < \phi^-(b), & or \\ \phi^+(a) = \phi^+(b) & and & \phi^-(a) < \phi^-(b), & or \\ \phi^+(a) > \phi^+(b) & and & \phi^-(a) = \phi^-(b). \end{cases} \tag{3.5}$$

- Indifference

$$aI^Ib, \quad if\left\{ \phi^+(a) = \phi^+(b) \quad and \quad \phi^-(a) = \phi^-(b).\right. \tag{3.6}$$

- Incomparability

$$aR^Ib, \quad if\left\{ \begin{array}{lll} \phi^+(a) > \phi^+(b) & and & \phi^-(a) > \phi^-(b), \quad or \\ \phi^+(a) < \phi^+(b) & and & \phi^-(a) < \phi^-(b). \end{array} \right. \tag{3.7}$$

It seems that, the application of the PROMETHEE I is possible to not classify alternatives in case that there are incomparable alternatives. Whereas, the PROMETHEE II performs complete ranking by calculating net outranking flow Figueira et al. [2005]:

$$\phi(a) = \phi^+(a) - \phi^-(a). \tag{3.8}$$

3.2 The Elimination and Choice Translating Reality Methods (ELECTRE)

This method is capable of handling discrete criteria of both quantitative and qualitative in nature and provides complete ordering of the alternatives. The problem is to be so formulated that it chooses alternatives that are preferred over most of the criteria and that do not cause an unacceptable level of discontent for any of the criteria. The concordance, discordance indices and threshold values are used in this technique. The index of global concordance C_ik represents the amount of evidence to support the concordance among all criteria, under the hypothesis that the alternative A_i outranks the alternative A_k, It is defined as follows:

$$C_{ik} = \frac{\sum_{j=1}^{m} W_j c_j(A_i, A_k)}{\sum_{j=1}^{m} W_j}. \tag{3.9}$$

where W_j is the weight associated with j_{th} criteria, and $c_j(A_i, A_k)$ is the outranking degree of alternative A_i and alternative A_k under criterion j.

The first *ELECTRE I* method, has a certain degree of imprecision, uncertainty and ill-determination as it only produce a core of leading alternatives. The next methods *ELECTRE IV* and *II* were designed to mitigate this inconvenience.

Finally, these three problems were actually overcome with *ELECTRE III*. The novelty of this method is the introduction of pseudo-criteria instead of true-criteria. The concept of the pseudo-criterion and its two thresholds (indifference and preference) allow all three phenomena to be taken into account. In *ELECTRE III* the outranking relation can be interpreted as a fuzzy relation. The construction of this relation requires the definition of a credibility index, which provides a judgment on degree of credibility of each outranking relation and represents a test to verify the performance of each alternative. The exploitation procedure used in *ELECTRE III* is generally as follows:

- Construct a complete pre-order Z_1.
- Construct a complete pre-order Z_2.
- Construct the partial pre-order $Z = Z_1 \cap Z_2$ as the final result.
- Z_1 and Z_2 are respectively constructed through a descending distillation procedure and an ascending distillation procedure.

Also, there is a fuzzy version of *ELECTRE III* method which uses the fuzzy theory in the two phases of decision making: evaluation of alternatives' performance and final ranking of alternatives based on their performance. This modified version of the *ELECTRE III* method not only can address the uncertainty of the alternatives performances but also is less complicated than the ordinary *ELECTRE III* method to be utilized. In other words, in order to tackle the uncertain problems, where the exact methods can rarely lead to a precise final answer, both phases of the decision process are needed to be able to deal with this uncertainty.

3.3 Analytical Hierarchy Process

The essence of the Analytic Hierarchy Process *(AHP)* Saaty [1980]is decomposition of a complex problem into a hierarchy with goal (objective) at the top of the hierarchy, criterions and sub-criterions at levels and sub-levels of the hierarchy, and decision alternatives at the bottom of the hierarchy. Elements at given hierarchy level are compared in pairs to assess their relative preference with respect to each of the elements at the next higher level. The verbal terms of the fundamental scale of 19 is used to assess the intensity of preference between two elements. Ratio scale and the use of verbal comparisons are used for weighting of quantifiable and non-quantifiable elements. The method computes and aggregates their eigenvectors until the composite final vector of weight coefficients for alternatives is obtained. The entries of final weight coefficients vector reflect the relative importance (value) of each alternative with respect to the goal stated at the top of hierarchy. To elicit pair wise comparisons performed at a given level, a matrix A is created in turn by putting the result of pair wise comparison of element i with element j into position a_{ji} as below:

$$A = \begin{bmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,n} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n,1} & a_{n,2} & \cdots & a_{n,n} \end{bmatrix}$$

Reciprocal value of the comparison is placed in a position a_{ji}.

The result of pairwise comparisons is weight coefficient for each element at given level, with respect to the element of a higher level. The weight coefficient of element is the measure of importance of the element for decision maker. Weight vector, consisting of weight coefficients for elements at given level, could be obtained by using different techniques (Saaty [1992]). After obtaining weight vector, it is then multiplied with the weight coefficient of element at higher level (that was used as criterion for pairwise comparisons). Procedure is repeated upward for each level, until the top of the hierarchy is reached.

Overall weight coefficient, with respect to goal, for each decision alternative is then obtained. The alternative with the highest weight coefficient value should be taken as the best alternative. One of the major advantages of *(AHP)* is that it calculates inconsistency index as a ratio of the decision makers inconsistency and randomly generated index Saaty [1980]. This index is important for the decision maker to asure him that his judgements were consistent and that final decision is made well. The value of inconsistency index lower than 0.10 is acceptable. Although higher value of inconsistency index requires re-evaluation of pairwise comparisons, decisions obtained in certain cases could also be taken as the best alternative.

The major advantage of the *(AHP)* is that it helps decision maker to cope with a problem complexity by decomposing problem into a hierarchical structure. The weights of decision criteria and the priorities of alternatives are determined by comparing only two elements at the time. Both qualitative and quantitative elements of the hierarchy are allowed to be pairwise compared with ease. To express the intensity of preference of one element over the other, verbal terms, numeric scale or graphic bars may be used, as far interactive seanse at computer is undertaken.

Finally, the analytic nature of *(AHP)* provides a clear rational for the choices that are being made. Its simplicity and intuitive logic facilitate the participation of various decision makers and even stimulate their involvement in brainstorming sessions which ultimatelly may improve collective thinking, reasoning, and the efficiency of group decision.

3.4 Comparison of the Multicriteria Analysis Methods

A review of published literature and bibliography presents that ELECTRE III, PROMETHEE I and II, AHP are the most popular MCDM methods in environmental planning. More particularly, ELECTRE III is widely used for choosing MSWM system even though the environmental data tend to be imprecise. As ELECTRE III has proved fairly insusceptible to variations in data and related parameters, an adequate amount of reliability can be expected of analyses carried about by means of it. On the contrary, the first methods of the ELECTRE family involve a high degree of risk if the environmental data on hand are unreliable or there was abrupt change from strict preference to indifference (characteristic of ELECTRE II). Also, these methods have difficulty to identify the preferred alternative and, consequently the process of ranking cannot be complete. ELECTRE III faces this problem by introducing thresholds on the criteria.

PROMETHEE methods are widely used due to its simplicity and capacity to approximate the way that human mind expresses and synthesizes preferences when facing multiple contradictory decision perspectives. This method has some strength in comparison with existing methods, such as AHP as, it has less pairwise comparisons and it does not have the artificial limitation of the use of the standard scale for evaluation. However, the essence of AHP method is more appropriate for the process of criteria weighting as the MSWM usually involves too many criteria that decision-maker has a difficulty to define weights for all the criteria. For this reason, many applications from the bibliography use AHP-PROMETHEE integrated approach for selection of the best alternative. First, the AHP method can be used to analyze the criteria in a hierarchical manner and determine the weights of criteria, whereas the PROMETHEE method can be used for final ranking. Usually, both PROMETHEE I and II are used for partial and complete ranking.

Thus, among the outranking MCDA methods widely applied in waste management problems, the application of the PROMETHEE method has been selected as the most suitable for the integration into DSS tool Briggs et al. [1990]; Kapepula et al. [2007]; Rousis et al. [2008]; Vego et al. [2008]. The goal of the particular technique, which belongs to the family of outranking methods is to create a structured process to identify objectives, create alternatives and compare them from different perspectives. Therefore, the particular method can be successfully applied to provide realistic solutions to such a complex problem as the MSWM and assist the decision makers to take into account a variety of other viewpoints apart from the costs.

Also, the selection of the particular method was based on analyzing the objectives of the DSS tool and the particular properties of its structure and functionality. It should be mentioned that, the DSS tool was designed targeting the non-specialists in the field of waste management, in result the preference information usually is not considered very clear and obvious for them and consequently, this task probably turns to be time-consuming and lacks of easy understanding to be performed successfully. More particularly, for each case study, data inserted and alternative scenarios selected by the user vary, resulting in the DSS tool to have to face different system considerations each time it is applied. Thus, the following properties of the PROMETHEE method are capable to overcome the aforementioned constraints in the functionality of the tool:

- the limited number and nature of thresholds are required for the pairwise comparisons within each criterion, in result empirical rule can be used avoiding the user involvement
- complete ranking of alternative scenarios, so that incomparability among scenarios is avoided.

Chapter 4

Guidelines for development of alternative waste management scenarios

As it was mentioned in the previous chapters a waste management plan has to be tailored according to the needs of the Region that it will be applied. However there are some common elements that are not region dependent such as the characteristics of the waste treatment technologies that will be integrated into the plan. Waste management planners have to identify how those technologies can be combined within technical and economical feasible combinations always taking the legislative restrictions into consideration. Also, taking into consideration the previous chapters, a considerable number of scenarios can be prepared for a specific area, taking into account that there are many available technologies and different approaches in waste management. For the purpose of this study, as well as for ensuring full compliance with the new EU Directive on waste, several assumptions have been considered.

These consist of the following:

- Packaging waste is collected and treated separately.
- Paper, metal, plastic, glass are separated at source either.
- Bio-waste is also separated at source.
- The overall recycling rate of municipal waste is 50% - this is considered as the maximum target set under the EU Directive.
- The overall diversion rate from landfills is 60%.
- The targets of Packaging and landfill Directive are fully met.
- Only the composting or anaerobic digestion of bio-waste collected through separation at source count towards the recycling targets.

- Obligatory separation at source and recovery of materials in a material recovery facility (plastic, paper, glass ,metal).

- Obligatory separation at source of biowaste and treatment in a biological treatment facility (composting or anaerobic digestion).

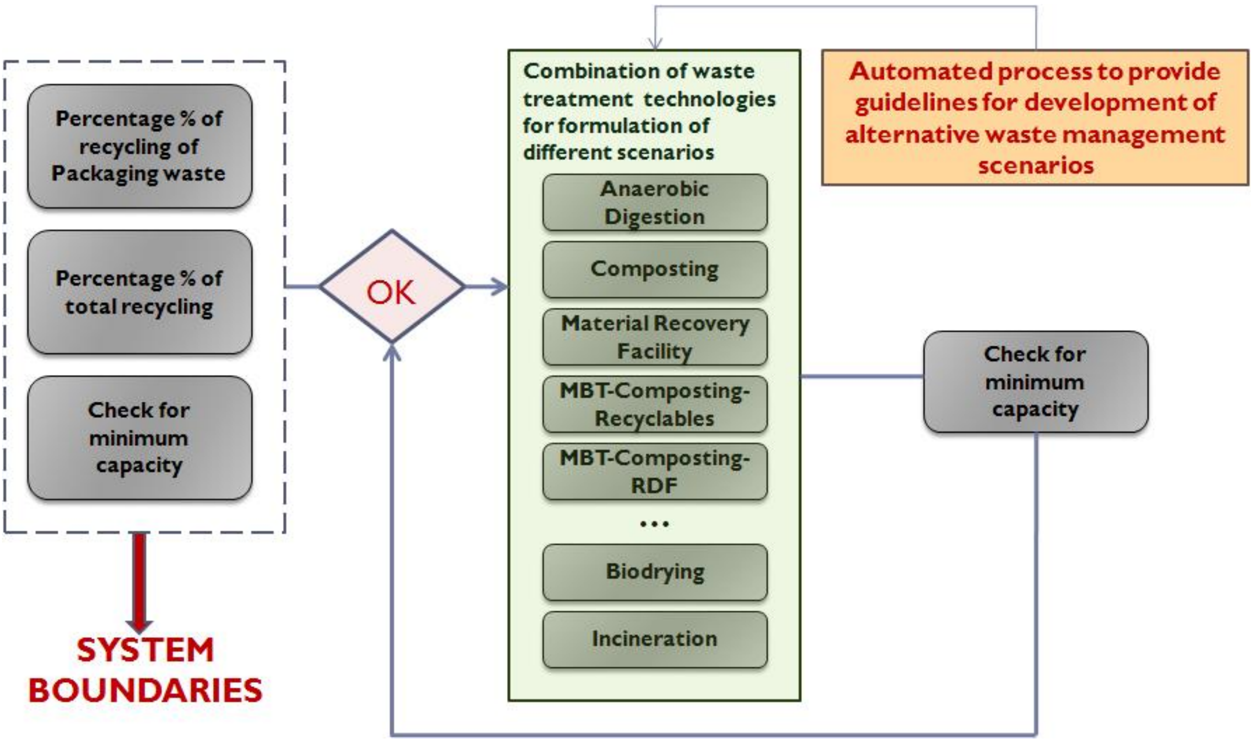


Figure 4.1: System Boundaries for formulation of scenarios

The formulation of alternative waste management scenarios is based on the selection of alternative waste management technologies. The scenario formulation procedure is accomplishing by taking under consideration all constrains and prerequisites that are related with certain MSW streams and the respective technologies. It also includes information related to the selected technologies operational parameters.

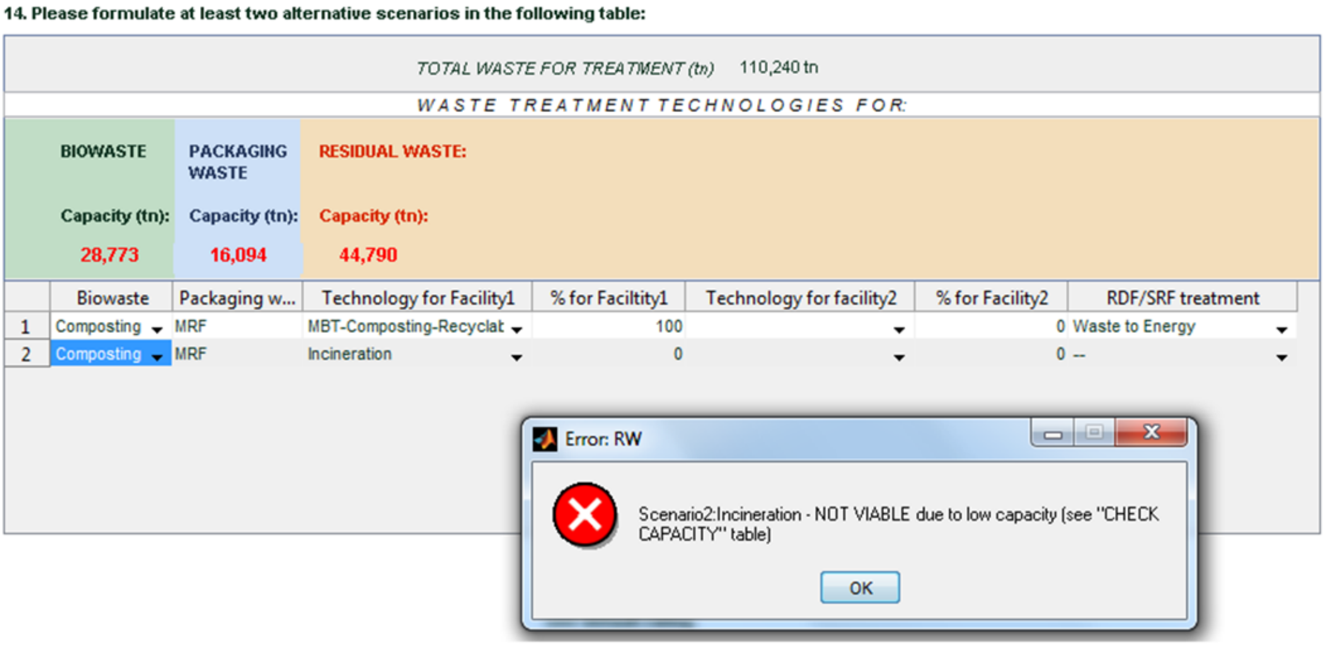


Figure 4.2: Error message box - not viable technology option is selected

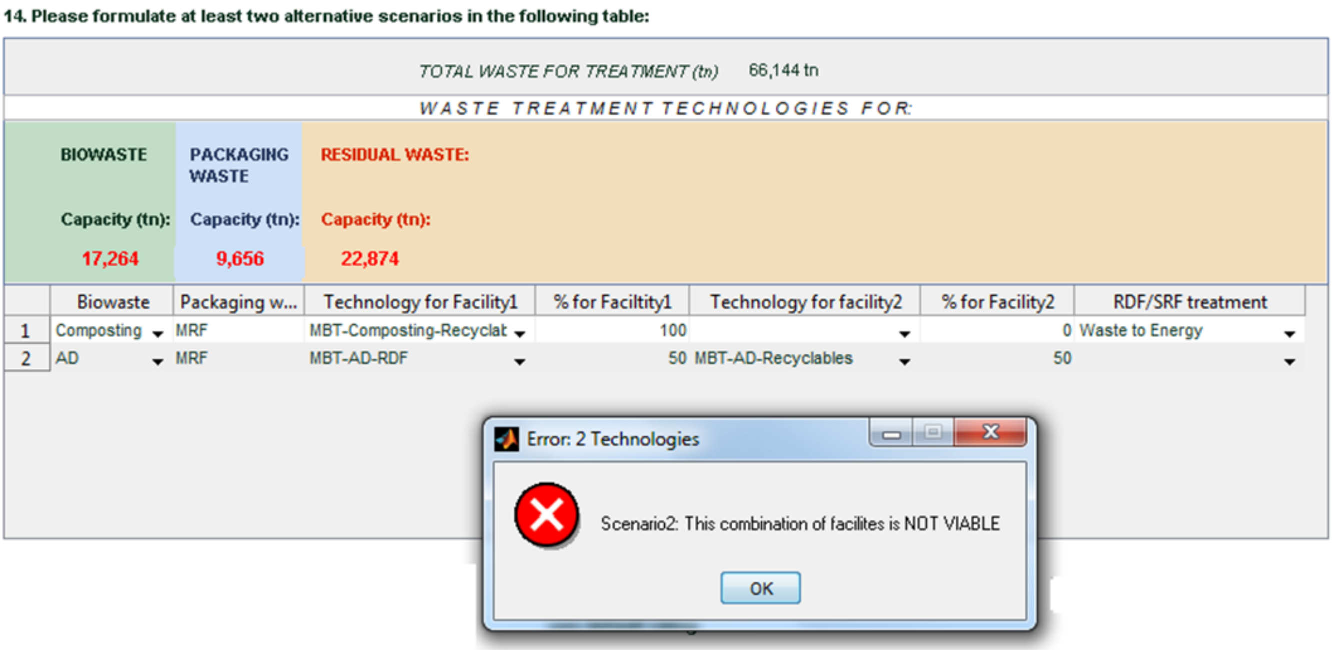


Figure 4.3: Error message box - not viable combination of two treatment technologies is selected

In order to create an alternative technology scenario the technologies that can be used for the treatment of certain MSW waste streams must first be clarified. These streams are referred to Source Separated Organic Waste (already described as BMW), Source Separated Packaging (already described as PW) and mixed MSW (already described as non separated MSW). According to the nature and the specific characteristics of each of the above mentioned MSW streams, the respective treatment technologies are:

- For the treatment of BMW:
  - Composting
  - Anaerobic Digestion (AD)
- For the treatment of PW:
  - Material Recovery Facility (MRF)
- For the treatment of mixed MSW - Mechanical Biological Treatment (MBT) which, according to the type of Biological Treatment and the final products of Mechanical Treatment, is further divided in:
  - MBT (Composting and Recyclables),
  - MBT (Composting, RDF and Metals).
  - MBT (AD and Recyclables),
  - MBT (AD, RDF and Metals),
  - Biodrying,
  - Incineration

For reasons related with the successful implementation of a waste management strategic plan, MBT technologies can be combined in order to achieve the optimum results as for the recycling and energy recovery from MSW. To this end, the implementation of a MBT will not be limited to one type but it can also include more than one type of the above mentioned MBTs. For example, during scenarios formation, a MBT besides of the Mechanical Treatment may include both Composting and AD for the organic residue. Furthermore, as for their locations, these MBTs may be at the same or at different sites.

Based on the results for viability of additional facilities (see Table 2.3, the DSS tool allows or rejects the selection of particular technologies (see Figure 4.2) or combination of technologies for the formulation of alternative scenarios (see Figures 4.1,4.3).

The interactive process of scenario formulation between the user and the DSS tool provides additional information about the minimum percentage (%) for the participation of the selected technology in order it to be able to be combined with the second technology.

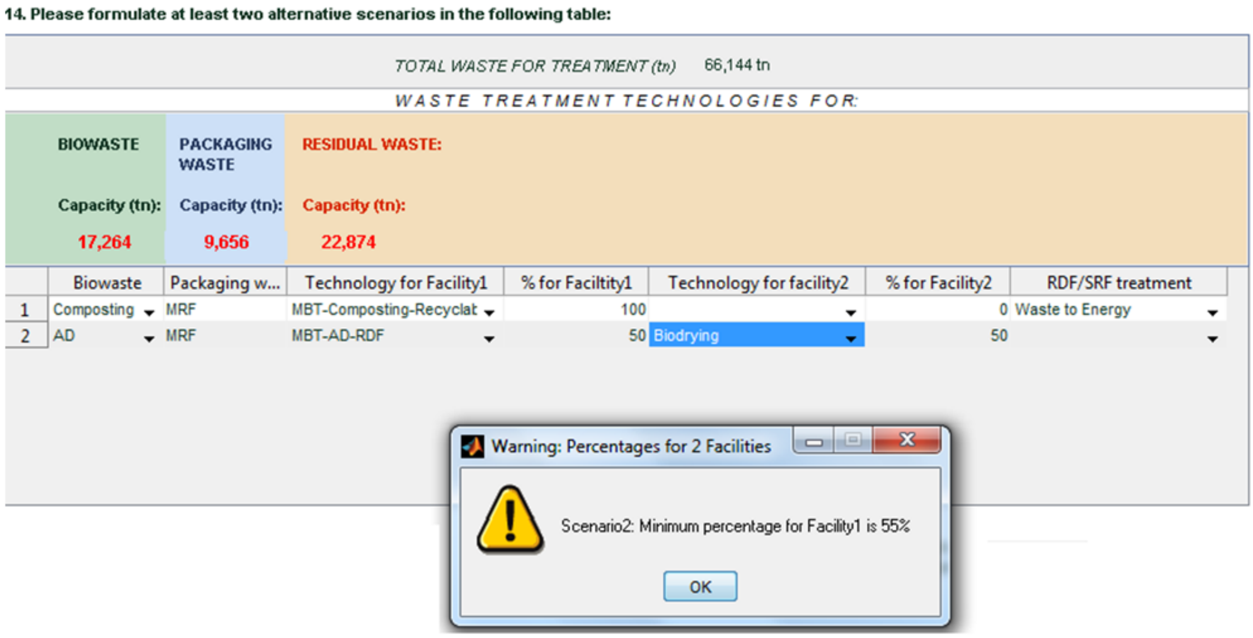


Figure 4.4: Warning message box for the user to increase % for the facility1

Finally, the key parameters that should be taken into account are the amounts of total waste, biowaste and packaging waste separated at source and residual waste to be treated at the year 2020, according to the prediction for waste generation for the planning period and the results from the validation process for minimum capacity.

Furthermore, in case that RDF and/or SRF are produced, the further disposal of the particular products is important to be defined through the DSS tool. For the the particular study, there are two options for RDF/SRF treatment:

- WasteToEnergy scheme such as:

  1. Co-incineration of RDF/SRF in a coal power plant or cement kiln.
  2. Combustion of RDF/SRF and MSW in incinerator

- RDF/SRF landfilling. In case WasteToEnergy scheme is not feasible - mainly due to technical, economical and regulatory constraints - and, consequently, there is no end-market (i.e. power plant or cement kiln) for SRF/RDF, the landfilling of RDF/SRF is the only waste treatment option

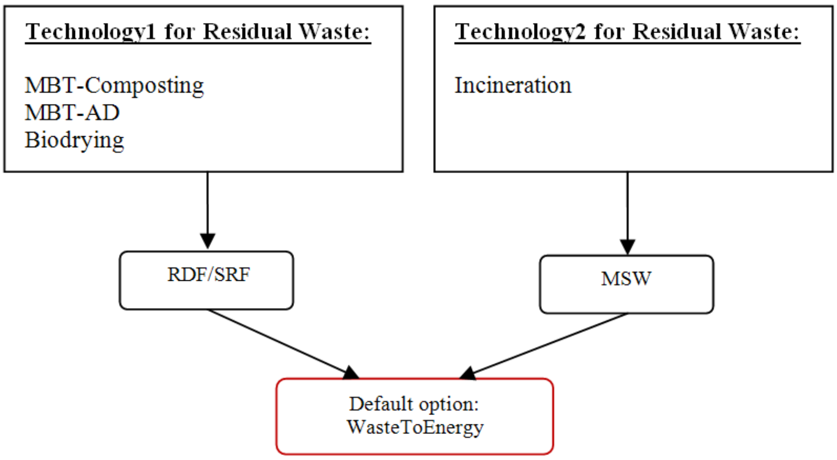


Figure 4.5: WasteToEnergy scheme-Combustion of RDF/SRF and MSW as default RDF/SRF treatment (Two technologies for RW: MBT-Incineration)

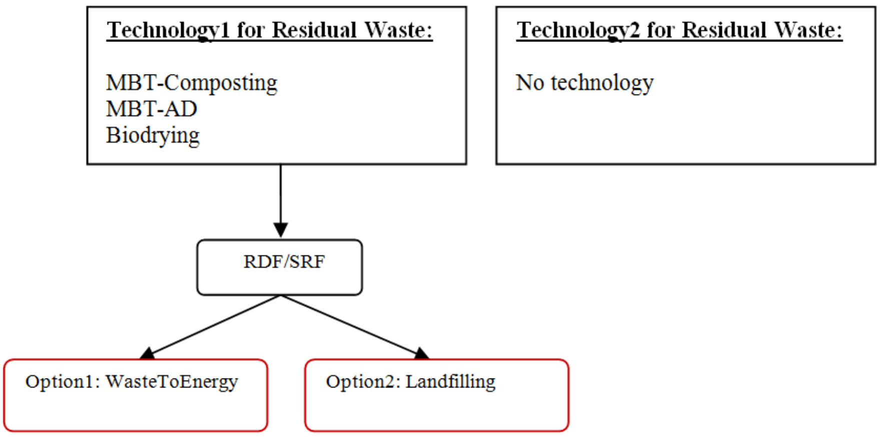


Figure 4.6: RDF/SRF treatment (One technology for RW: MBT)

Apart from the aforementioned important parameters, possibility for promotion of the final products of formulated scenarios (compost, recyclables, energy recovery, etc) to the end market with or without revenues is considered and should be defined through the DSS tool, as well (see Figure 4.8).

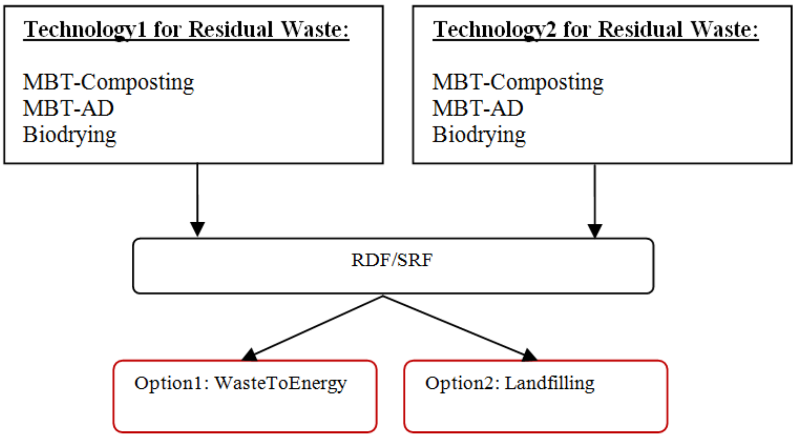


Figure 4.7: RDF/SRF treatment (Two technologies for RW: MBT-MBT)

REVENUES FROM SALE OF RECYCLABLES:	
1. Fe (euro/tn)	150
2. Al (euro/tn)	400
3. PLASTIC (euro/tn)	70
4. PAPER (euro/tn)	30
--	
REVENUES FROM SALE OF ENERGY (euro/MWh):	120

Figure 4.8: Input data for revenues from products (Greece)

The particular possibility is based on the existing prospects for sale of end products from waste for the case study region or country. Especially, the revenues from energy recovery from waste strongly depend on the existing legislative regulations and subsidies for renewable energy or energy by waste. According to the Greek regulation for the prices for biodegradable derived energy for the use of biogas from biomass (scenarios including anaerobic digestion), values range from 120 €per MWh (for installed power $\leq$ 2MW) and 99,45 €per MWh (for an installed capacity $>$ 2MW). The revenue from the sale of electricity in thermal treatment units, equals to 87,85 €per MWh according to the provisions of the respective regulation on energy use but only for the percentage of the biodegradable fraction of MSW. However the exact calculation method for incineration is still under consideration since no such facilities operate in Greece. In Bulgaria and Romania no subsidies for electrical energy from waste are in effect. In Slovenia the prices are regulated through the regulation on the supports for the electricity generated from renewable energy sources.

Chapter 5

Evaluation of alternative scenarios and criteria weighting

For the purpose of evaluation of scenarios, Material Flow Analysis (MFA) is performed for each technology participated in the scenarios. MFA is an analytical method for quantifying flows and stocks of materials and substances, so that an analytical account of various visual outputs is provided. In the present study, the final outputs of MFA are derived from mass balance, analysis for costs and revenues, energy balance and evaluation of environmental impacts, based on certain data such as Waste composition, Waste Generation, Recycling rate per waste stream and waste treatment technologies selected for formulation of alternative scenarios.

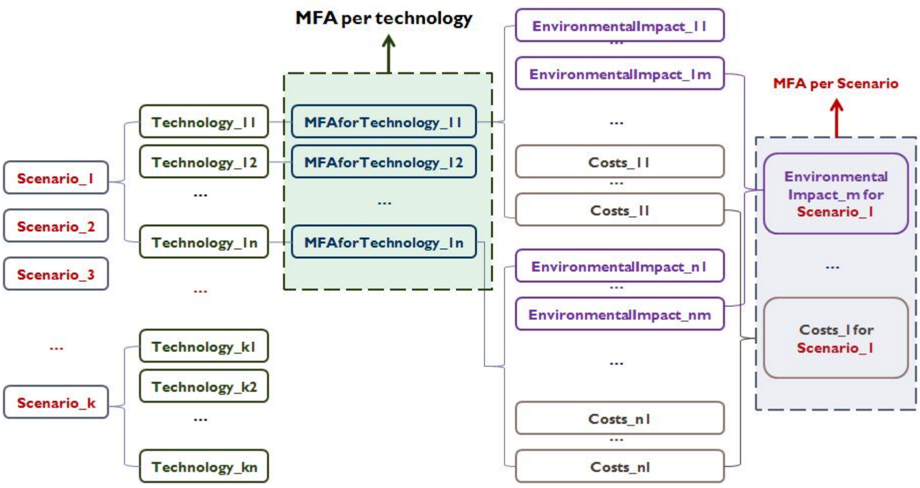


Figure 5.1: Flow diagram for Material Flow Analysis

More analytically, the process of MFA is performed automatically by DSS tool and provides the following results:

- Final products that are emerged from the application of each technology, such as amounts of compost, recyclables, SRF/RDF amounts, and etc.

- Final outputs as proportions of the processed MSW stream (mass balances)

- Economic data for each technology such as Capital expenditure, Operational and maintenance costs, Revenues from final products, Land requirement, Disposal costs

- Operational parameters such as energy consumption and energy production

- Environmental Impacts, including GHG emissions, Emissions to air, Conventional fuel savings, Water consumption, Production of hazardous and non-hazardous waste.

After the MFA per technology is completed, the DSS tool aggregates the corresponding MFA outputs for all technologies which formulate the scenario (see Figure 5.1), in order to produce the corresponding MFA outputs per scenario, which can be visualized through the DSS tool.

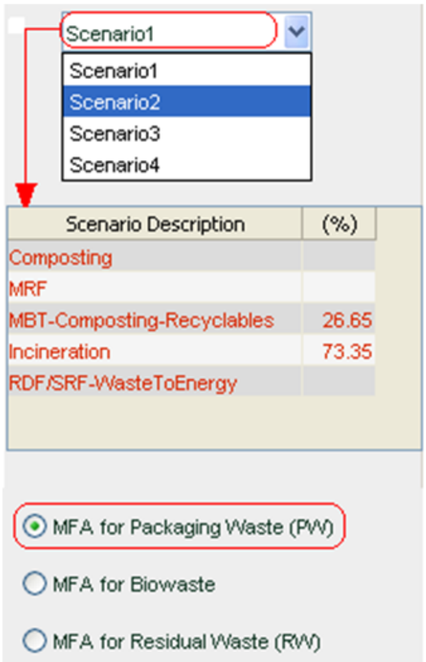


Figure 5.2: Selection of scenario and type of waste for MFA projection

Furthermore, the DSS tool provides the ability to visualize graphically the outputs of MFA per scenario and for each waste stream separately (see Figure 5.2). For example, Figure 5.3 shows MFA results for Residual waste treatment plant.

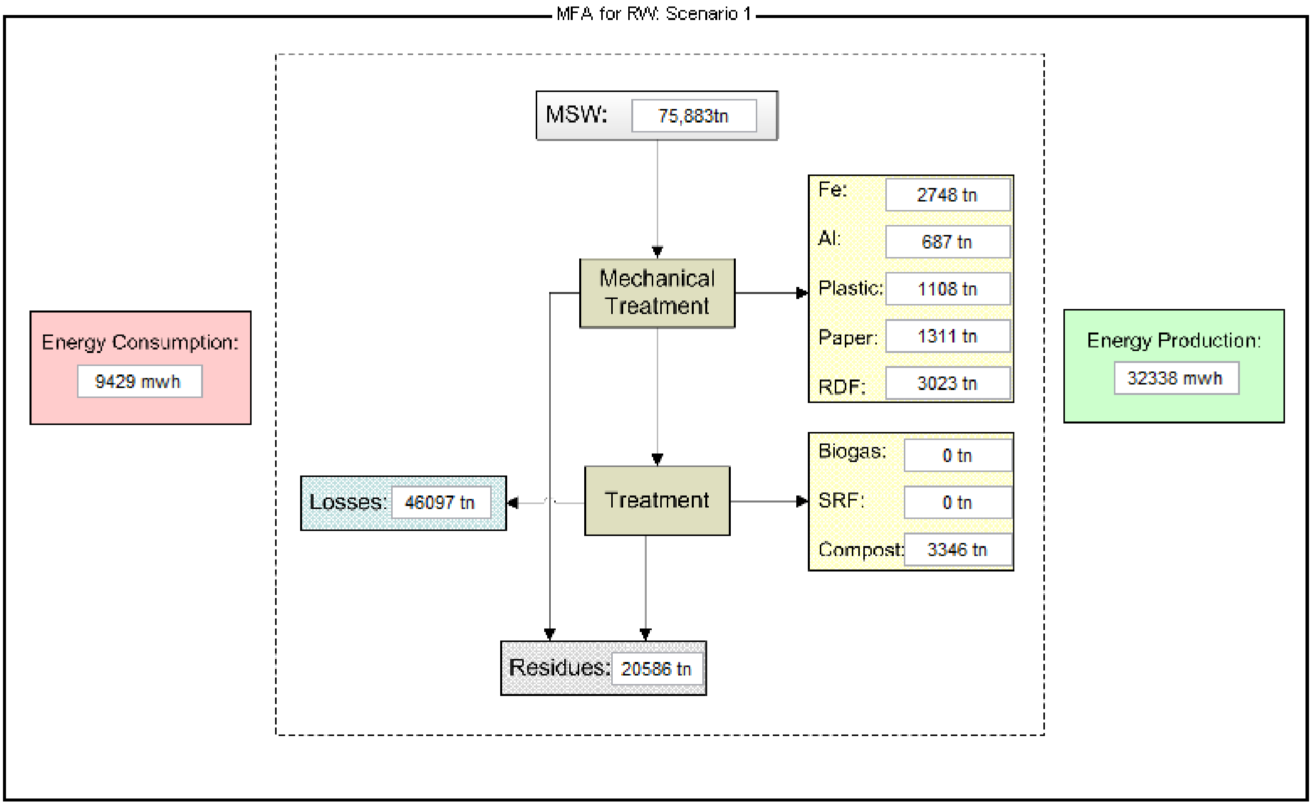


Figure 5.3: An example of MFA outputs for Residual waste treatment per scenario

For the purpose of the comparative assessment of alternative scenarios, Economical, Environmental, Technical, Social and Legislative criteria have been developed Den Boer et al. [2007]; EUROCONSULTANTS S.A [2011b]; Rousis et al. [2008]. It should be mentioned that, the major part of the outputs from MFA were included in the set of the quantitative criteria. For example, the MFA output "Revenues from products" defines the criterion with the same title. In the present study, criteria are separated into quantitative and qualitative criteria, according to the type of measurement scale used to express the performance of alternatives. It is important to notice that, for the particular study, each criterion is expressed in its own units taking into account that the evaluation of alternatives for each criterion which represents the qualitative information is based on the evaluation scale Hokkanen and Salminen [1997].

The DSS tool provides default evaluations per technology for each qualitative criterion, which rely on the studies concerning waste management status in Balkan countries EUROCONSULTANTS S.A [2011b] (see Tablle 5.1). However, the user can modify these evaluations by changing the rating/evaluation in the scale (0-100) per waste treatment technology. Calculation of total average rating/evaluation per waste treatment scenario formulated for each qualitative criteria is implemented by DSS the tool according to the Eq. 5.1).

$$ScenarioRating_i = \sum_{k=1}^{n} \frac{TechnologyRating_i(k)}{n}; \tag{5.1}$$

where i a qualitative criterion; k a technology participated in the scenario rating for criterion i; and n a number of technologies participated in the scenario rating for criteria i.

Table 5.1: Proposed evaluations of waste treatment technologies for qualitative criteria

Qualitative Criteria	Tech.1	Tech.2	Tech.4	Tech.5	Tech.6	Tech.7	Tech.8	Tech.9
Ql(1)	100	100	50	50	60	60	20	0
Ql(2)	20	80	20	20	50	50	20	20
Ql(3)	20	20	40	40	40	40	40	100
Ql(4)	90	70	80	80	50	50	70	70
Ql(5)	80	80	80	80	80	80	50	50
Ql(6)	80	60	80	80	50	50	70	50
Ql(7)	0	0	70	70	70	70	40	30
Ql(8)	70	70	70	70	70	70	70	20
Ql(9)	40	60	40	40	60	60	50	80
Ql(10)	20	20	30	30	30	30	40	60
Ql(11)	50	60	50	50	80	80	60	80
Ql(12)	60	60	40	40	40	40	40	40
Ql(13)	80	100	60	60	80	80	20	20
Ql(14)	0	0	80	80	80	80	100	100

More particularly, the rating method requires the user to evaluate the technologies for the quantitative criteria on the basis of a predetermined scale (0-100). The purpose of using a wide scale range from 0 to 100, in contrast with the evaluation scale usually applied in other studies (usually up to 10 points scale Hokkanen and Salminen [1997]; Rousis et al. [2008]; Tsoutsos et al. [2009]), is to cope with intermediate points of the fluctuations of performance between "low" and "very high" and additionally to provide a relatively easy way of rating choices for the involved actors. In this case, there is a need to correspond the intermediate points with a verbal scale (see Table 5.2).

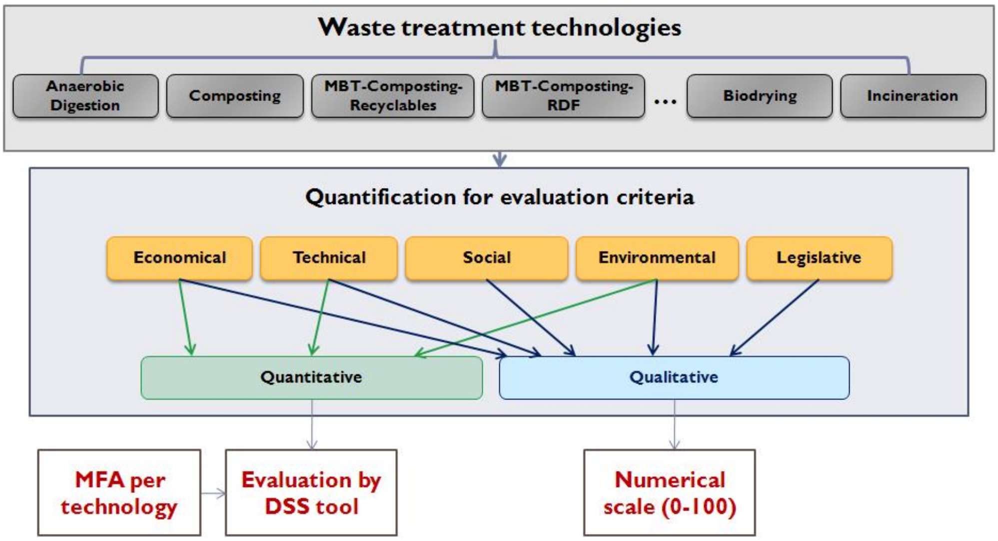


Figure 5.4: Quantification for evaluation criteria

Furthermore, it is important to mention that, there are quantitative and qualitative criteria, for which the high mark has negative effect, such as costs, emissions to air, visual impact, employment quality, etc., meaning that the particular criteria should be minimized by the DSS tool. Whereas other criteria with cohesive relation, for which high score implies high performance/positive effect should be maximized by the DSS tool. For this reason, the verbal scale, shown in the Table 5.2 is simply reversed for the criteria to be minimized, so that very high performance corresponds to 0-25 of numerical scale, high performance to 26-50, moderate performance to 51-75 and low performance to 76-100.

Table 5.2: Use of a verbal scale for the rating method for the criteria to be maximized

Verbal scale	**Numerical scale**
Very high performance	76-100
High performance	51-75
Moderate performance	26-50
Low performance	25-0

As evaluations of scenarios for the quantitative criteria (e.g. Operational Cost (€), Land requirement (m^2), Emissions to Air (tn eq. SO_2)) have quantitative measures, they are evaluated by the DSS tool without the user involvement, with the use of the results from MFA per scenario (see Figure 5.4).

After the scenarios have been scored towards the defined set of criteria, the next step is the process of criteria weighting. The method of weight assignment is indirect, meaning that it is performed by means of properly questionnaires distributed to the different waste management authorities involved.

Table 5.3: Established set of qualitative and quantitative criteria for comparative assessment of different waste management scenarios

Criteria Index	Criteria	Average Rating	Proposed Weights	Weights Group 1	Weights Group 2	min/max function
	Economical Criteria					
Qnt(1)	Capital Expenditure (€/tn)	80	6.06%	5%	5.1%	minimize
Qnt(2)	Operation& Maintenance Cost (€/tn)	80	6.06%	5%	5.1%	minimize
Qnt(3)	Revenues from Products (€/tn)	70	5.30%	4.38%	5.73%	maximize
Qnt(4)	Land Requirement (m^2/tn)	10	0.76%	0.63%	3.82%	minimize
Ql(1)	Market Prospect of Products (1-100)	50	3.78%	3.13%	5.1%	maximize
Qnt(5)	Environmental Externalities - External Costs and Benefits (€/tn)	20	1.52%	1.25%	1.91%	minimize
	Environmental Criteria					
Qnt(6)	Greenhouse Gas Emissions (tn CO_2 eq./tn)	60	4.55%	5%	3.82%	minimize
Qnt(7)	Emissions to Air (tn SO_2 eq./tn)	60	4.55$	5%	3.82%	minimize
Qnt(8)	Conventional Fuel Savings (toe/tn)	30	2.27%	4.38%	1.91%	minimize
Ql(2)	Wastewater Generation (1-100)	10	0.76%	1.88%	0.64%	minimize
Qnt(9)	Water Consumption (m^3/tn)	20	1.52%	2.5%	1.27%	minimize
Qnt(10)	Production of non-hazardous Solid Waste-Residues (tn)	60	4.55%	5%	3.82%	minimize
Qnt(11)	Production of Hazardous Residues (tn)	40	3.03%	3.13%	2.55%	minimize
Ql(3)	Noise Pollution (1-100)	10	0.76%	1.25%	0.64%	minimize
	Technical Criteria					
Ql(4)	Existing Experience Reliability (1-100)	50	3.78%	3.13%	4.46%	maximize
Ql(5)	Adaptability to local Conditions (1-100)	50	3.78%	3.13%	5.1%	maximize
Ql(6)	Flexibility (1-100)	40	3.03%	2.5%	3.18%	maximize
Qnt(12)	Energy Consumption (kwh/tn)	50	3.78%	3.13%	5.1%	minimize
Qnt(13)	Energy Production (kwh/tn)	50	3.78%	3.13%	5.1%	maximize
Qnt(14)	Secondary Products (tn)	60	4.55%	3.75%	4.46%	maximize
Ql(7)	Correlation with recycling activities (1-100)	60	4.55%	3.75%	4.46%	maximize
	Social Criteria					
Ql(8)	Social Acceptance (1-100)	70	5.30%	5%	4.46%	maximize
Ql(9)	Visual Impact (1-100)	10	0.76%	3.13%	0.64%	minimize
Ql(10)	Risk Perception (1-100)	40	3.03%	2.5%	2.55%	minimize
Ql(11)	Employment Quality (1-100)	20	1.52%	3.13%	1.27%	minimize
Ql(12)	Creation of New Jobs (1-100)	20	1.52%	3.75%	1.27%	maximize
	Legislative Criteria					
Ql(13)	Harmonization with the Priorities of the EU Legislation (1-100)	100	7.57%	6.25%	6.37%	maximize
Ql(14)	Contribution to the Landfill Directive Targets (1-100)	100	7.57%	6.25%	6.37%	maximize
	SUM	1320	100%	100%	100%	

In order to achieve a classification of the evaluation criteria all active actors involved in waste management, such as Ministry of Environment, Regional Environmental Agencies, Local Environmental Agencies, Public and Private Sanitation operators, County Councils were informed about the weighting process of criteria in the case study countries. The cooperation of the evaluation team with the aforementioned actors provided all the elements needed to calculate global weighted scores for each criterion. In most cases, weighting of the criteria were proposed by the evaluator or negotiated by the addressees of the evaluation and finally decided to establish average weightings, which has the effect of effacing different points of view among the actors.

Thus, the proposed average weights are indicative and may vary significantly according to the needs of each waste management authority (see Table 5.3). For this reason, the user is provided with the ability to modify default weights or use different weights to each criterion. Once the user determines the value $(1-100)$ for a criterion, the DSS tool calculates the corresponding weight in percentage (%) based on normalization of the weights for all the criteria so that the sum of the weights always to result 100%. Moreover, the user has the ability to set default weights to some groups of criteria and at the same time to modify the ratings/weights to another.

5.1 Determination of Preference Function and Preference, Indifference Thresholds for the PROMETHEE II method

In order to apply the PROMETHEE II method, additional information is needed regarding the preference function and preference thresholds. There are six types of preference function with corresponding preference and indifference thresholds, which should be defined for each criterion in order the deviations among alternative scenarios can be evaluated (see Figure 5.5). As it has been mentioned, the important constraint which arises from the application of the DSS tool is that, as the input data are different for each case study, and choices for alternatives, ratings of technologies and weights vary for different users, the evaluations on alternatives are not fixed. Moreover, as the DSS tool was designed for non-specialists in waste management and Multicriteria Analysis, the involvement of the decision-makers in the definition of preference functions and thresholds should be avoided. For these reasons, an automated process must be performed for the implementation of Multicriteria Analysis, concerning the selection of preference and indifference thresholds for the PROMETHEE II method.

More particularly, for the qualitative criteria, the V-shape Preference function *with Indifference Criterion* has been selected Figueira et al. [2005]. Preference threshold has been set in 25 points, as the levels within the scale (1-100) are well-defined (e.g. very high performance is different from high performance in 25 points, high performance is different from moderate performance in 25 points, etc.), whereas, the indifference threshold is set to 10 points, considering the usual deviations in evaluations of particular criteria. The linear part of this function expresses linear preference for intermediate points of scale, in case that the deviation of evaluations is less than 25 points and more than 10.

On the other hand, for the quantitative criteria V-shape preference function, *without Indifference Criterion*, is used with the preference threshold set to 25% on the maximum deviation $max\left[d_j(a,b)\right]$ between the evaluations on the particular criteria Rousis et al. [2008]; Tsoutsos et al. [2009]. This empirical rule is used as the evaluations on the qualitative criteria are not fixed (i.e. no scale is used, each criterion is evaluated in its own units)

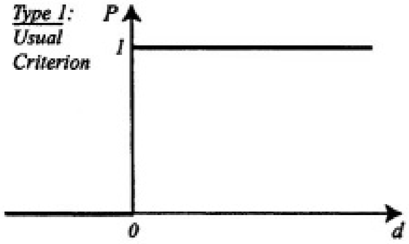
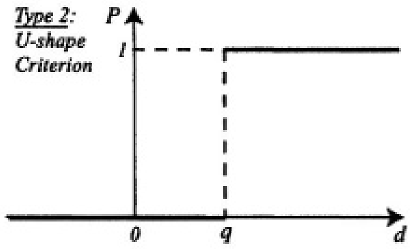
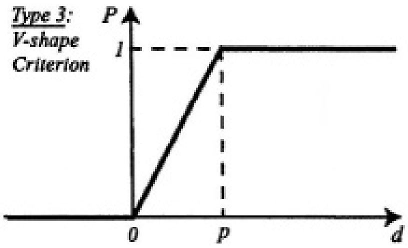
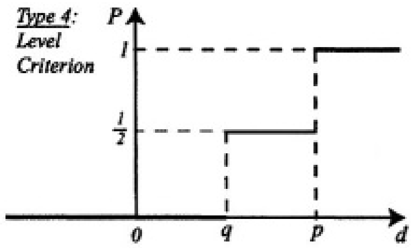
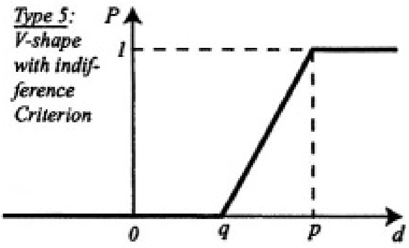
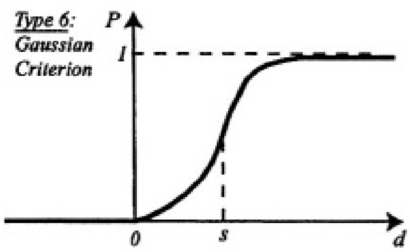
Generalised criterion	Definition	Parameters to fix
Type 1: Usual Criterion 	$P(d) = \begin{cases} 0 & d \leq 0 \\ 1 & d > 0 \end{cases}$	–
Type 2: U-shape Criterion 	$P(d) = \begin{cases} 0 & d \leq q \\ 1 & d > q \end{cases}$	q
Type 3: V-shape Criterion 	$P(d) = \begin{cases} 0 & d \leq 0 \\ \frac{d}{p} & 0 \leq d \leq p \\ 1 & d > p \end{cases}$	p
Type 4: Level Criterion 	$P(d) = \begin{cases} 0 & d \leq q \\ \frac{1}{2} & q < d \leq p \\ 1 & d > p \end{cases}$	p, q
Type 5: V-shape with indifference Criterion 	$P(d) = \begin{cases} 0 & d \leq q \\ \frac{d-q}{p-q} & q < d \leq p \\ 1 & d > p \end{cases}$	p, q
Type 6: Gaussian Criterion 	$P(d) = \begin{cases} 0 & d \leq 0 \\ 1 - e^{-\frac{d^2}{2s^2}} & d > 0 \end{cases}$	s

Figure 5.5: Types of preference function for the application of the PROMETHEE II method

Chapter 6

The structure of Decision Support System tool

The development of the software tool in the present work was based on the need for the well-defined parts of waste management planning, which should be clearly connected with the evaluation and comparative assessment of different waste management scenarios. For this purpose, it was important to develop the basic structure of the whole work, as described in the previous chapters, which could be integrated into the DSS tool (see Figure 6.1) with the following parts:

- basic input data for the target area, such as demographical data, waste characteristics, existing waste management practices, special characteristic of case study area EUROCONSULTANTS S.A [2011c].

- designing of alternative waste management scenarios EUROCONSULTANTS S.A [2011a].

- visualization of Material Flow Analysis for Cost and Environmental Impacts, Mass balance and Energy Balance per scenario and per waste management facility (facilities for Biowaste, Packaging waste (Material Recovery Facility (MRF)) and Residual Waste are available).

- rating of different waste treatment technologies by user

- definition of weights by user for evaluation criteria which will be used for comparative assessment of different waste treatment scenarios EUROCONSULTANTS S.A [2011b]

- visualization of final ranking performed by Multicriteria analysis

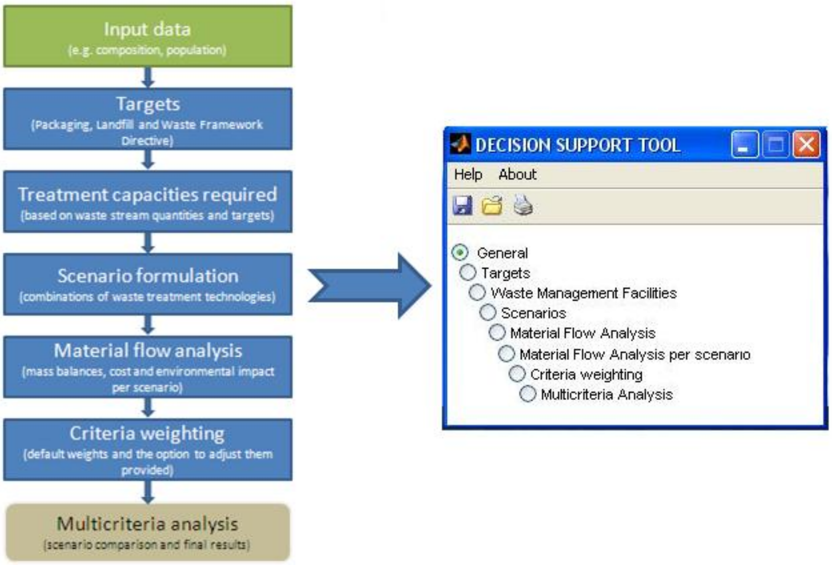


Figure 6.1: Integration of the basic structure of the decision support system into the DSS tool

6.1 Graphical User Interface

DSS tool is developed using MATLAB®graphical user interface environment. After developing the Graphical User Interface (GUI), a standalone distributable application (exe) for Windows Operational System is created, using MATLAB Compiler, allowing executions on computers with no MATLAB installed.

Initially, user is provided with the DSS tool folder containing all required programs and files for installing and executing the application:

- Instructions.txt; instruction notes on the installation
- vcredist_x86.exe; the Microsoft Visual C++ 2008 Redistributable Package (x86), which installs runtime components of Visual C++ Libraries required to run applications developed with Visual C++
- MCRinstaller.exe; DSStool.exe. MATLAB Compiler Runtime (MCR) is a runtime engine, allowing MATLAB compiled programs to execute without MATLAB installed. It works in a similar way to the Java Virtual Machine (allows the execution of java scripts), and contains a series of *.dll and various other files, that are able to interpret and execute a program written in the MATLAB language. MCR version must be in accordance to the version of MATLAB used to compile the DSS tool.

- RatingsForTechnologies.xls; rating/score (0-100) assigned to each waste treatment technology for the set of qualitative criteria. The qualitative and quantitative criteria, which are automatically evaluated by DSS tool using user data for waste characteristics and infrastructure, are used for comparative assessment of different waste management scenarios formulated by user.

Figure 6.2: Entering the program

In order to install the DSStool.exe, vcredist_x86.exe and MCRinstaller.exe must already be installed. It is important to mention that, these programs are installed only once on each computer. After these installations, double click on DSStool.exe to open it. First, a command prompt window will appear after a short period of time (depending on the machine), (see Figure 6.2).

The minimum system requirements for installing and running the standalone application of DSS tool are suggested below:

- Windows 2000, XP 32-bit/64-bit, 2003, Vista 32-bit/64-bit, Windows 7 32-bit/64-bit
- At least 512 RAM
- At least 1GHz Processor

- At least 1024x768 pixels screen resolution

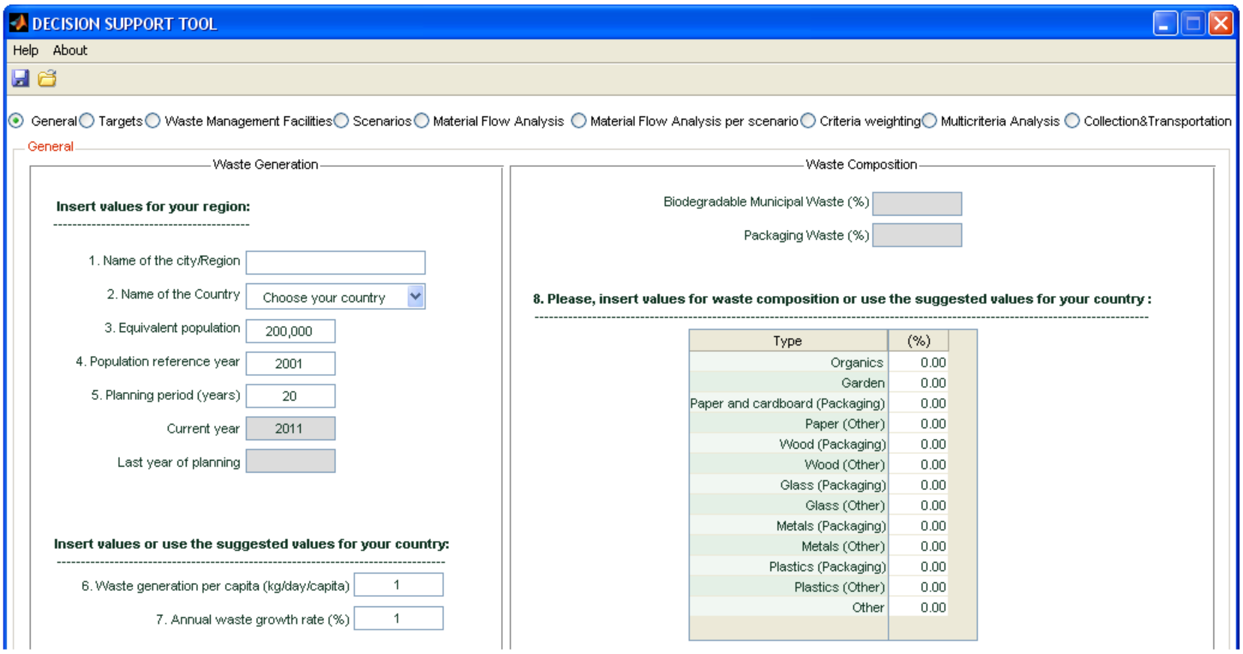


Figure 6.3: The workspace of DSS tool

When the program opens, the DSS tool workspace appears, which consists of the following taxonomy of panels (see Figure 6.3):

- “General”
- “Targets”
- “Waste Management Facilities”
- “Scenarios”
- “Material Flow Analysis”
- “Material Flow Analysis per scenario”
- “Criteria Weighting”
- “Multicriteria Analysis”
- “Collection & Transportation”

The above taxonomy has been defined according to the type of input data required by user. The particular structure of DSS tool assists the user to perceive the input and output data flow and interactions between the components (e.g. how the targets for Recycling in “Targets” panel depends on data inserted in “General” panel).

6.1.1 Data flows

It is important to notice that, waste management planning using the DSS tool heavily depends on the input data inserted by user in the following panels:

- Waste generation panel
- Waste composition panel
- Targets panel
- Waste Management Facilities panel

In case the input data in the above panels are altered, the DSS tool will reset the Scenarios Table (see Figures 6.4 and 6.5), even if the waste management scenarios in the “Scenarios” panel have already been formulated, since it is considered that the waste management planning must change due to different amounts of waste to be treated and, consequently, new scenarios must be formulated by user. All the panels following the Scenarios panel, except for “Criteria weighting” must be reset as well.

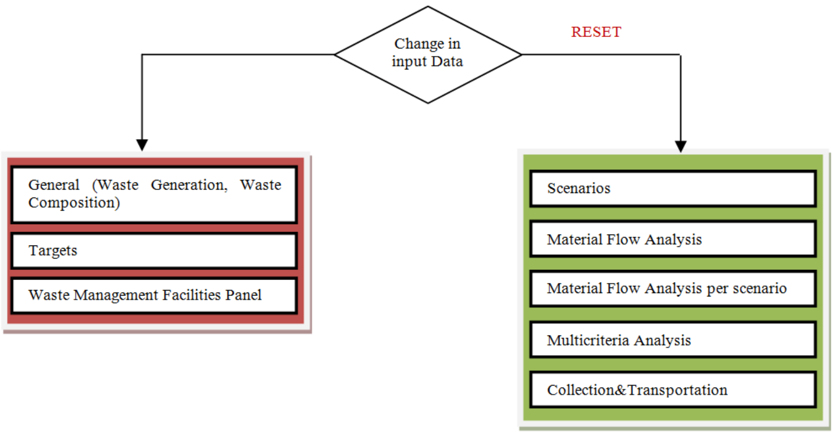


Figure 6.4: How the changes in the input data inserted by user, influence the data flow in DSS tool

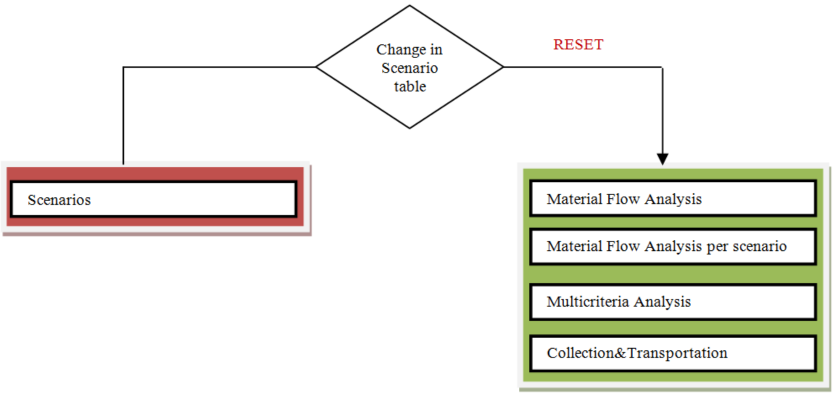


Figure 6.5: How the changes in the Scenario table inserted by user, influence the data flow in DSS tool

6.1.2 Save/Open/Export case studies

In order to save user settings and data inserted in the DSS tool, there is a “Save” option in the Toolbar. The file “caseStudy.mat” can be saved on the different directory from the DSStool.exe parent directory, but the file type has to be “.mat” (see Figures 6.6 and 6.7).

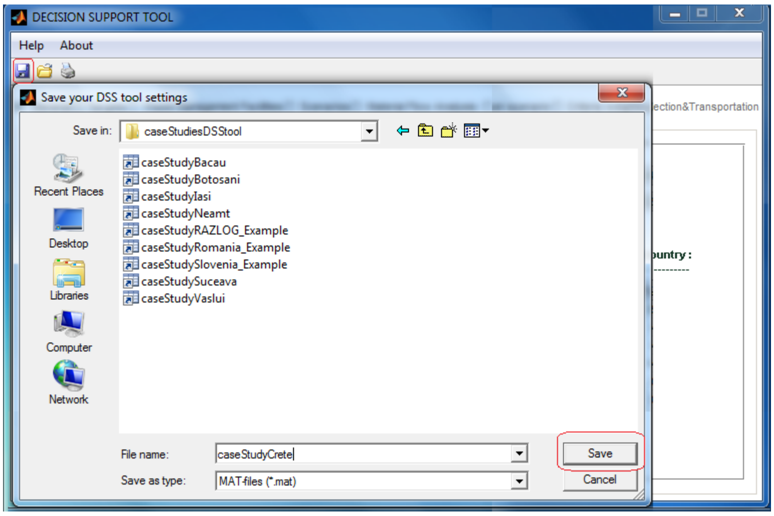


Figure 6.6: How to save a case study of DSS tool

In order to open the “caseStudy.mat” file, DSStool must be running. After the workspace of DSStool has appeared on the screen, “Open” option in the Toolbar should be used for opening the particular file.

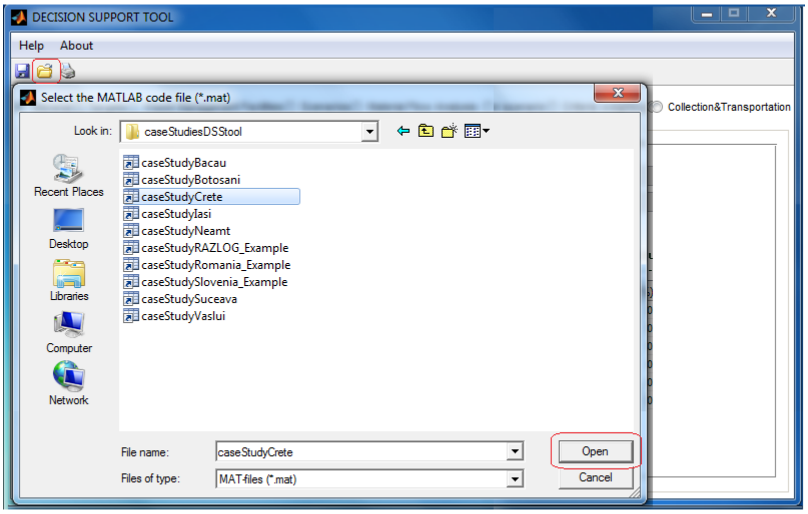


Figure 6.7: How to open a case study of DSS tool

To export a case study in “html” format, “Export” option in the Toolbar should be used. In this case, a folder named “DSS_reports”, which contains the report will be created in the same directory as the DSStool is initiated (Figure 6.8). Note here, that even if the case study has not been fully developed, a partial report will be created.

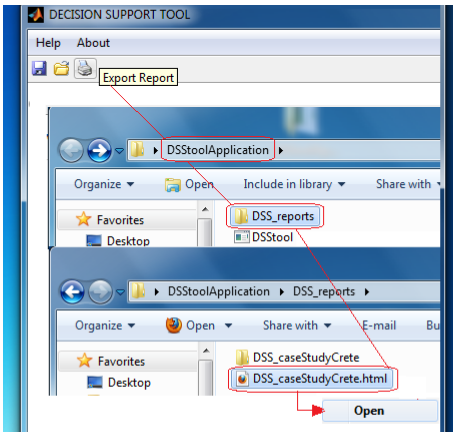


Figure 6.8: How to export a case study of DSS tool

6.1.3 Usual User Errors

Towards valid performance of DSS tool, exception functions have been developed to detect possible user errors. Usual errors have been categorized — in the following chapters a brief description for each category is provided. Moreover, if an error is detected, all the panels, except for the current panel, are set inactive until the error is corrected.

Missing input data

Attempting to continue to the next panel without inserting all the required data triggers an error, communicated by a message box, as shown in Figure 6.9.

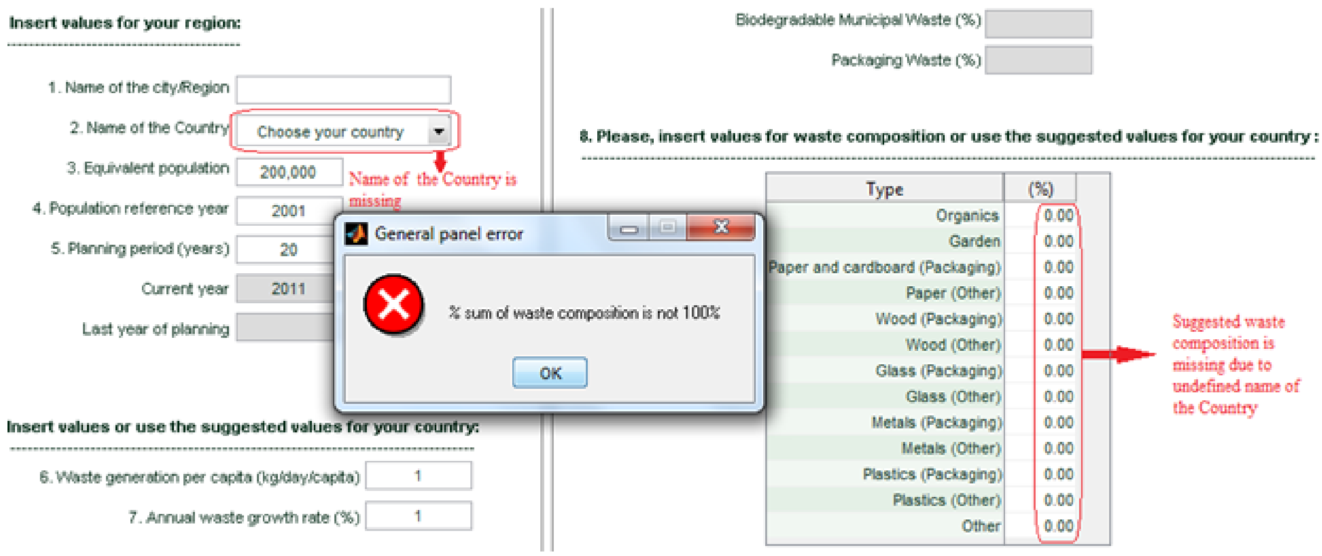


Figure 6.9: Error message for sum of waste composition due to undefined user's country

Value inserted is not a number

In case the value inserted is not a number (e.g. character), a relative message box will appear on the screen (Figure 6.10).

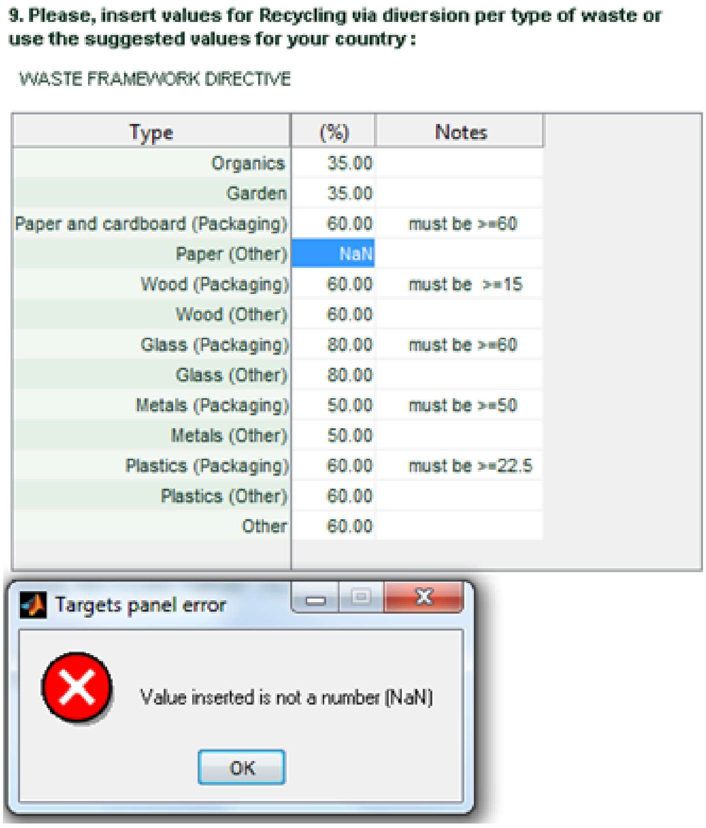


Figure 6.10: Error message for inserting value, which is not a number

6.2 Application of Decision Support Software Tool for the Case Study of Attiki urban waste district, Greece

Basic input data such as demographical data, waste characteristics, existing waste management facilities, as well as additional characteristics, such as revenues from energy recovery (€/MWh) and revenues from sale of recyclables (€/tn), etc.) for the region of Attiki are defined in EURO-CONSULTANTS S.A [2010]. In order to base the formulation of waste management scenarios on realistic assumptions, it was important to consider some techno-economical and social aspects of waste infrastructure in Greece.

Figure 6.11: Waste management scenarios formulated for the case study of Attiki, Greece

More particularly, the existing waste treatment facilities for MSW rely on the MBT method, while the construction of biological treatment plant has been planned for the treatment of source separated organics in the Attiki region. Also, only one biodrying facility started its operation in Heraklion of Crete (Greek island), a few years ago. Furthermore, problems exist with the utilization of the RDF and SRF production; in result the RDF/SRF amounts are either stored or used in landfilling operations. For formulating the waste treatment scenarios, the available technologies for the treatment of residual waste could be separated in MBT methods and non-MBT methods (Biodrying, Incineration). Although the waste incineration still is not acceptable in Greece due to negative social opinion, the waste incineration participates in formulation of scenarios. Also, from available MBT methods, those with the maximum production of RDF (MBT-Composting/AD-RDF) are excluded due to the existing problems of RDF utilization EUROCONSULTANTS S.A [2010]. Thus, two MBT methods for residual waste with the minimum production of RDF, such as MBT-Composting-Recyclables and MBT-AD-Recyclables, are combined with Composting and AD for source separated Biowaste to produce four different scenarios. The amounts of RDF or SRF (Biodrying) of the five formulated scenarios, except for incineration of residual waste with no RDF/SRF production, are selected to be landfilled (see Figure 6.11).

Moreover, default ratings for waste treatment technologies are selected to evaluate each qualitative criterion per technology (see Table 5.1). The capacity of existing facility for treatment of Packaging waste (MRF Tech.3, see Table 2.3) in the region of Attiki can treat all the amount of source separated packaging waste. In result, there is no need for the additional capacity for MRF. Also, for the case study of Attiki, Greece the proposed average EU and country specific prices are used for the sale of recyclables, compost and electrical energy derived from waste, as it has been described in the previous section (see Figure 4.8).

Table 6.1: Quantification of the alternative scenarios for evaluation criteria formulated for the case study of Attiki, Greece.

Scenario	**Qnt(1)**	**Qnt(2)**	**Qnt(3)**	**Qnt(4)**	**Qnt(5)**	**Qnt(6)**	**Qnt(7)**
1st	329.588.474	71.447.870	21.694.809,51	641.632	-5.379.050,51	-1.944.741	-656
2nd	177.981.126	49.369.130	6.724.856,52	420.845	1.924.996,76	-1.852.116	303
3rd	526.825.218	82.487.240	6.724.856,52	273.653	1.924.996,76	-2.478.295	1.960
4th	183.868.790	45.689.340	11.097.014,31	788.824	4.769.108,69	-1.920.766	-548
5th	378.935.966	78.116.450	27.592.057,09	552.718	-12.247.687,91	-184.458	-729
6th	233.216.282	52.357.920	16.994.261,89	699.909	-2.099.528,71	-160.483	-621
	Qnt(8)	**Qnt(9)**	**Qnt(10)**	**Qnt(11)**	**Qnt(12)**	**Qnt(13)**	**Qnt(14)**
1st	2.240	55.272	382.046	0	67.768	88.315	384.424
2nd	15.656	11.114	536.627	0	111.926	0	513.478
3rd	-61.076	84.710	205.446	36.798	111.926	401.833	108.701
4th	9.260	29.513	382.046	0	53.049	0	384.424
5th	-2.512	70.832	382.046	0	71.102	138.107	373.310
6th	4.508	45.073	382.046	0	56.383	49.792	373.310
	Ql(1)	**Ql(2)**	**Ql(3)**	**Ql(4)**	**Ql(5)**	**Ql(6)**	**Ql(7)**
1st	80	35	30	70	80	65	70
2nd	60	20	30	80	65	75	40
3rd	50	20	60	80	65	65	30
4th	75	20	30	85	80	80	70
5th	80	65	30	60	80	55	70
6th	75	50	30	75	80	70	70
	Ql(8)	**Ql(9)**	**Ql(10)**	**Ql11)**	**Ql(12)**	**Ql(13)**	**Ql(14)**
1st	70	50	25	65	50	80	80
2nd	70	45	30	55	50	50	100
3rd	45	60	40	65	50	50	100
4th	70	40	25	50	50	70	80
5th	70	60	25	70	50	90	80
6th	70	50	25	55	50	80	80

Finally, after the evaluation of alternative scenarios for the established set of criteria has been completed (see Table 6.1) and the criteria weights have been set to default values for the case study of Attiki, Greece Multicriteria Analysis is performed by the applying the PROMETHEE method. User has the possibility to visualize the results of complete ranking both numerically (*Net Flow* in ascending order) and graphically, which show the dominance of the *Scenario4* over the rest of alternative scenarios. Also, the negative *Net Flow* of the *Scenario2* and the *Scenario3* shows that the *Negative Flow* is higher than the *Positive Flow*, in result the particular alternatives are more outranked on all the criteria. Moreover, analyzing the results, it should be noticed that, the use of Composting for the treatment of source separated biowaste provides advantage to the highest ranked scenarios towards the use of AD. Whereas, the technology of "MBT-Composting-Recyclables" outranks all the other participating technologies for the treatment of residual waste.

In conclusion, although the DSS tool provides the solution based on the complete ranking of alternatives, the existing experience of the involved actors for the possible constraints and specifications of the case study region – which are difficult to integrate in a model such as the DSS tool – should be combined with the final outputs, so that practical and realistic solution can be provided.

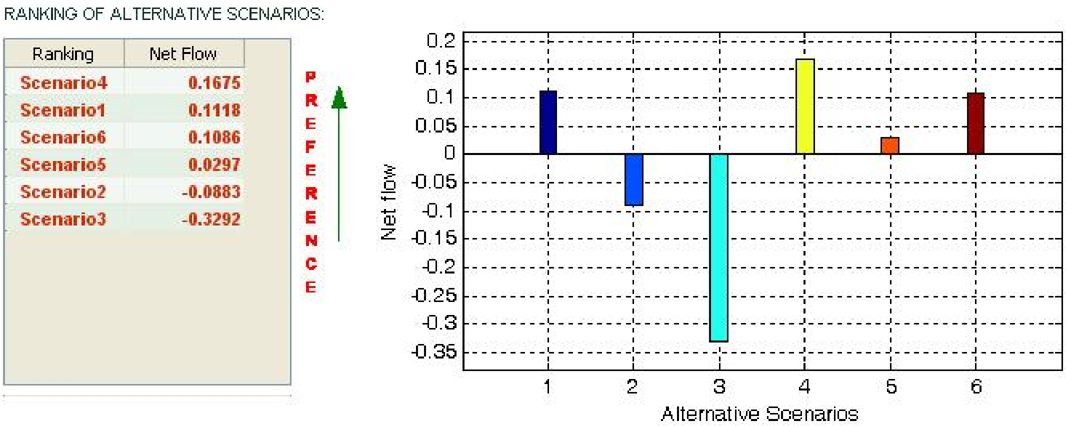


Figure 6.12: Complete ranking for proposed set of criteria weights for the region of Attiki

6.3 Application of Decision Support Software Tool for the Case Study of Crete

For the application of the DSS tool for the case study of Crete actual data were mined from a waste management strategic plan providing the report entitled Validation of the DSS Tool for the Case of Crete BALKWASTE LIFE+ Project [2009]. These data were related with quantitative and qualitative characteristics and information regarding the existing waste management infrastructure for the management of MSW generated in the island of Crete. The alternative scenarios consist of AD or Composting technology for the treatment of source separated biowaste, MRF for the treatment of source separated packaging waste and "MBT-Composting-Recylables" or/and Incineration technologies for the treatment of mixed MSW (see Figure 6.13).

Also, the RDF amounts, which produced by MBT plants are combusted in the incinerator with the rest of the residual waste for the energy recovery. For this reason and for the further treatment of RDF amounts "Waste to Energy" scheme is selected by default through the DSS tool (see Figure 6.13).

Moreover, default ratings for the participating technologies (Tech.1-4, Tech.8, Tech.9 – see Table 2.3) are selected to evaluate each qualitative criterion per technology (see Table 5.1). Moreover, for the case study of Crete, Greece the proposed average EU and country specific prices are used for the sale of recyclables, compost and electrical energy derived from waste, as it has been described in the previous section (see Figure 4.8).

Figure 6.13: Waste management scenarios formulated for the case study of Crete

Table 6.2: Quantification of evaluation criteria for the alternative scenarios formulated for case study of Crete

Scenario	Qnt(1)	Qnt(2)	Qnt(3)	Qnt(4)	Qnt(5)	Qnt(6)	Qnt(7)
1^{st}	62.058.849,11	12.276.319,03	6.272.211,21	109.484,37	661.300,29	-629.775	85
2^{nd}	75.711.183,11	14.121.229,03	7.903.726,62	84.885,57	-1.238.957,01	-142.780	65
3^{d}	36.121.205,00	9.493.310,00	6.558.972,18	148.446,50	872.343,21	-595.264	-106
4^{th}	49.773.539,00	11.338.220,00	8.190.487,59	123.847,70	-1.027.914,09	-108.269	-126
	Qnt(8)	**Qnt(9)**	**Qnt(10)**	**Qnt(11)**	**Qnt(12)**	**Qnt(13)**	**Qnt(14)**
1^{st}	-4.423	9.146	37.942	2.783	14.588,	32.338	128.671
2^{nd}	-5.738	13.451	37.942	2.783	15.511	46.113	125.597
3^{d}	-368	4.972	37.996	0	9.712	0	152.859
4^{th}	-1.683	9.277	37.996	0	10.635	13.775	149.784
	Ql(1)	**Ql(2)**	**Ql(3)**	**Ql(4)**	**Ql(5)**	**Ql(6)**	**Ql(7)**
1^{st}	50	20	53	80	70	70	50
2^{nd}	50	40	53	73	70	63	50
3^{d}	75	20	30	85	80	80	70
4^{th}	75	50	30	75	80	70	70
	Ql(8)	**Ql(9)**	**Ql(10)**	**Ql11)**	**Ql(12)**	**Ql(13)**	**Ql(14)**
1^{st}	53	53	37	60	47	53	90
2^{nd}	53	60	37	63	47	60	90
3^{d}	70	40	25	50	50	70	80
4^{th}	70	50	25	55	50	80	80

Finally, after the evaluation of alternative scenarios for the established set of criteria has been completed (see Table 6.2) and the criteria weights have been set to default values for the case study of Crete, Greece Multicriteria Analysis is performed by the application of the PROMETHEE method. The results show that *Scenario3* and *Scenario4* outrank *Scenario1* and *Scenario2*. Also, the *Net Flow* of *Scenario3* shows that the particular scenario is the highest ranked alternative. In addition, the final ranking shows similar results with those for the case study of Attiki. More particularly, the use of Composting for the treatment of source separated biowaste and “MBT-Composting-Recylables” technology shows strong dominance over the other technologies. Both Greek cases show that, the particular combination of technologies consists the optimum scenario with the best overall rating on its technical, environmental, economic, social and legislative performance.

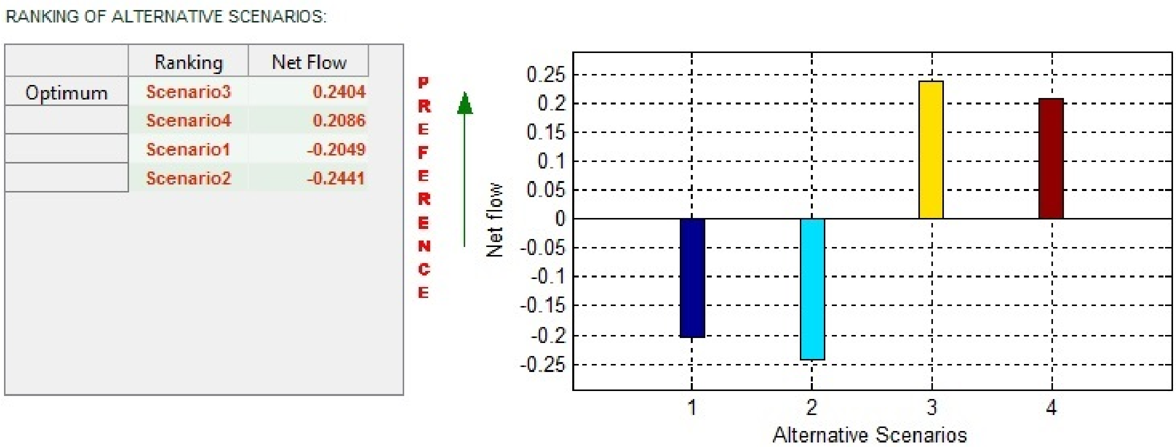


Figure 6.14: Complete ranking for proposed set of criteria weights for the region of Crete

6.4 Analysis of the impact of the application of different sets of criteria weights

After MFA has been completed, the users are allowed to modify the criteria weights, in order to acquire an insight on how the final ranking is affected, i.e. at which extend the *Net Flow* and the final ranking of the alternative scenarios are influenced by the preferences of the decision-makers. To this direction and in order to investigate the strength of the outranking relation among the scenarios according to the decision-maker preferences, the involved actors in cooperation are asked to perform modifications of the default weights.

As the decision makers (as not DSS experts) are interested in the final outcome of the modification of a group of weights, they are allowed to modify default values (average ratings) for the criteria weights of the group of socio-environmental criteria (Group 1) and the group of techno-economical criteria (Group 2). In contrast, the legislative group of criteria is fixed to default values by all actors (see Table 5.3). For the purpose of the particular study, apart from the default criteria weights, two different sets of weights (Groups 1 and 2, see Table 5.3) were selected for the Multicriteria Analysis for the region of Attiki and the Crete island, Greece.

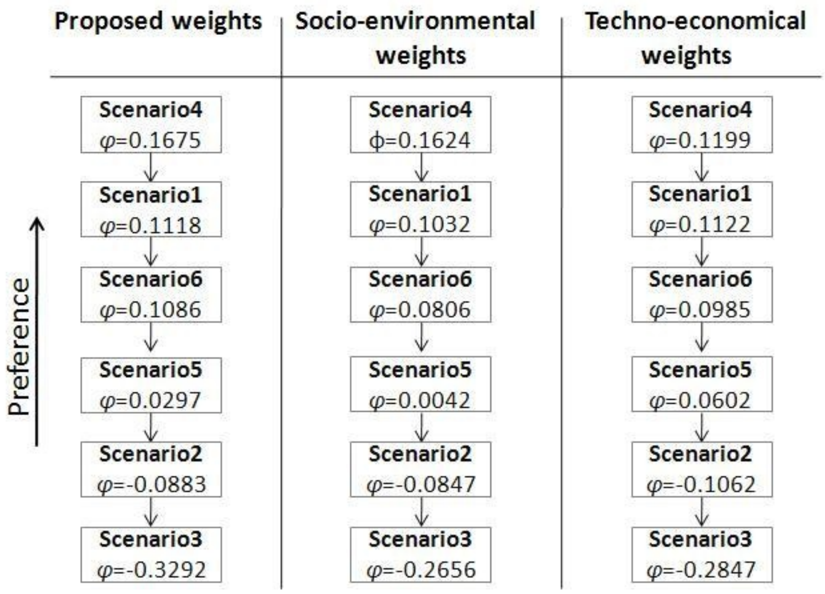


Figure 6.15: Application of the different sets of weights for the region of Attiki

More particularly, after applying the socio-environmental and techno-economical sets of weights for the region of Attiki the original ranking of the scenarios doesn't change (see Figure 6.15), while *Scenario4* and the order of all alternatives are insensitive to particular changes in weights. More analytically, Figure 6.15 shows that the *Net Flow* of the *Scenario4* is influenced negatively by the techno-economical set of weights, thus, *Scenario1* (*Net Flow=0.1122*) could be considered almost equivalent to *Scenario4* (*Net Flow=0.1199*), whereas, for the socio-environmental and proposed weights the *Scenario4* shows almost the same dominance over the rest of scenarios.

Similarly, after applying the socio-environmental sets of weights for the Crete island the original ranking of the scenarios doesn't change (see Figure 6.16), whereas, applying techno-economical sets of weights, the ranking of the first pair of scenarios (*Scenario3*, *Scenario4*), and the second pair of scenarios (*Scenario1*, *Scenario2*) is reversed. The particular results show that *Scenario4* and *Scenario2* (AD technology) perform better for the techno-economical criteria, as the particular technology provides more techno-economical benefits, rather the socio-environmental.

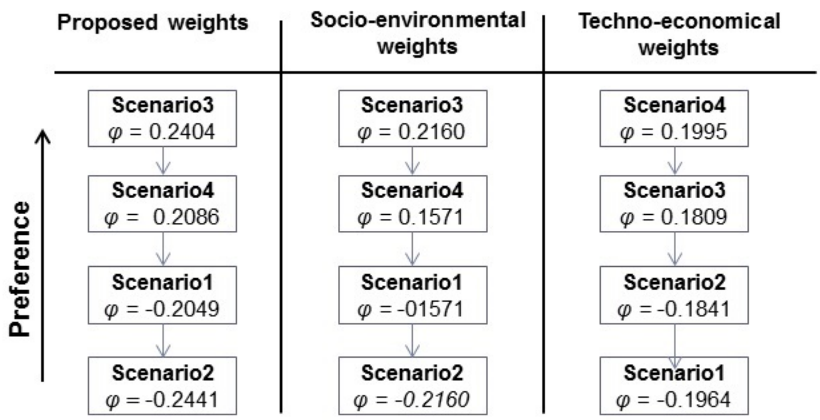


Figure 6.16: Application of the different sets of weights for the case study of Crete

6.5 Discussion and Conclusions

The applications of the presented interactive DSS tool for the region of Attiki and the island of Crete clearly show that MBT methods for residual waste present strong dominance against the other technologies, such as Biodrying and Incineration. The particular results confirm the existing waste management status in Greece since the construction and operation of MBT plants has been promoted successfully to various regions of Greece at least the last decade. For this reason, according to the evaluation of waste treatment scenarios by the DSS tool, it seems that the decision-makers have to decide for the type of MBT plant, rather than selecting different technology from MBT. In this case, as the existing treatment plants have problems with the utilization of secondary products (RDF/SRF production), which leads to extra disposal costs instead of revenues, MBT plants with minimization of RDF production and maximum recovery of Recyclables should be preferred.

However, the evaluation performed by the DSS tool can be easily changed, in case that the aforementioned problems are solved and consequently, new data for waste management status should be inserted. For this reason, despite the fact that each step of DSS tool has been automated, the degree of involvement of the decision-maker is small but important, especially in the process of formulation of different scenarios and regarding the preference values and qualitative information, which express his/her social point of view and thus, making the process of decision-making more realistic and efficient.

One of the major objectives set for the development of the DSS tool was the simplicity of the tool, so that non-specialists in the field of waste management can participate in designing and assessing various waste management schemes against the defined set of criteria.

Also, in real world, decision-makers usually show little interest in the applicability of the method used for the assessment of alternatives. For this reason, the complete ranking is provided, instead of results of partial and complete ranking. Similarly, default weights and evaluations for qualitative criteria are proposed in order to avoid laborious and time-consuming process of evaluation required by the user.

Moreover, it was given a great importance to the design of graphical user interface (GUI) of the DSS tool, taking into account that the user must be attracted to use the DSS tool by its user-friendliness BALKWASTE LIFE+ Project [2009]. As far as the application of the PROMETHEE II method in the present case study, it seems that its major advantage towards other multicriteria methods lies in its simplicity, that is easily obtained and understood by both decision-makers and analysts. Additionally, the application of the DSS tool provides the valuable possibility to test the algorithm, by changing various preference parameters and visualizing the influence of these parameters on the final ranking.

Finally, we have to emphasize here that the objective of the DSS tool is not to provide an optimal solution, but to offer decision-makers a knowledge-exchange platform assisting the evaluation of the different waste management scenarios, considering a variety of preferences and perceptions, thus, resulting in effective and reliable decision-making processes even for complex problems, such as the MSWM. It important to mention that, although DSS tool focuses mainly on Balkan countries, can scale to any country. However, the structure of DSS tool allows functionality expansion to different geographical areas, having different waste characteristics, thus resulting to a generic tool for supporting decision-making in waste management planning.

ANNEX

Alternative waste treatment methods

After identifying the targets that are to be met and the existing situation regarding waste quantities, composition and existing infrastructures is clarified, the technical alternatives for the fulfillment of the targets have to be identified. In the following paragraphs a short summary of the available waste treatment technologies is presented.

Material Recovery Facilities

Source separated waste is transferred to materials recovery facilities (MRF) for sorting. A MRF is a specialized plant that receives, separates and prepares recyclable materials for marketing to end-user manufacturers. A MRF accepts recyclable mixed (commingled) materials that have been separated at source from municipal solid waste generated, mainly using mixed recyclable materials bins. Materials are sorted to specifications, then baled, shredded, crushed or otherwise prepared for shipment to market.

Composting Facilities

In terms of municipal solid waste management composting facilities usually process bio-waste collected after the implementation of separation at source collection schemes together with green waste. The end-product of the composting process is the compost which has the potential to be used as a soil amendment in various applications. Compost can substantially improve the fertility, texture, aeration, nutrient content and water retention capacity of the soil. Due to its beneficial characteristics, compost has a variety of potential applications and can be used by several market segments.

Anaerobic Digestion Facilities

In terms of municipal solid waste management anaerobic digestion facilities usually process bio-waste collected after the implementation of separation at source collection schemes.

The end products of an anaerobic digestion facility consist of biogas and digestate. Biogas is a mixture of various gases. Biogas can be utilized for the generation of electricity and heat that cover primarily the energy needs of the facility. Surplus electricity energy is supplied to the local grid. Digestate is the solid end product of the process and contains raw organic material that cannot be used by the microorganisms and the bacteria. It can be treated through a composting step in order to produce compost.

Anaerobic digestion offers significant a significant advantage in comparison to composting through the production of renewable energy but AD plants are more complex to operate and their capital and operational cost is increased. The decision for or against an AD plant is mainly governed by the subsidies offered for the renewable energy produced. In Greece and Slovenia the prices on the energy produced from the digestion of the biodegradable fraction of MSW are given in the Law 3851/2010 on "Accelerating the development of Renewable Energy Sources to deal with climate changes and other regulations addressing issues under the authority of the Ministry of Environment, Energy and Climate Change" and the Regulation on supports for the electricity generated from renewable energy sources (No. 37/2009). In Romania the legislation regulates the production of energy from these resources, but, so far, only applies to solar, wind and hydro. In Bulgaria the prices for the alternative energy providers exist only for photovoltaics, water power stations and stations using wood pellets and agricultural waste.

Mechanical Biological Treatment

Regarding mixed waste, sorting of recyclables can be achieved in a similar way to a MRF but with a different and more intense technical configuration since the recyclable fraction has to be first separated from the wet organics and even then several organic and other impurities have to be removed. As a result the final quality of the separated materials is low. The separated organics will have to be treated in a biological treatment plant using composting (MBT-Aerobic plant)or anaerobic digestion technology (MBT-Anaerobic plant).

Incineration

The incineration (combustion) of carbon-based materials in an oxygen-rich environment (greater than stoichiometric), typically at temperatures higher than 850_o, producing a waste gas composed primarily of carbon dioxide (CO_2) and water (H_2O). Other air emissions are nitrogen oxides, sulfur dioxide, etc. The inorganic content of the waste is converted to ash. The object of this thermal treatment method is the reduction of the volume of the waste with simultaneous utilization of the contained energy. The recovered energy could be used for:

- heating
- steam production
- electric energy production

The method could be applied for the treatment of mixed solid waste as well as for the treatment of pre-selected waste. It can reduce the volume of the municipal solid waste by 90% and its weight by 75%.

Incineration is an effective way to reduce the final volume of waste ending up in landfills. The high capital and operational expenditure is a hindrance for the construction and operation in the Balkan Countries. Only large facilities that achieve economies of scale and serve larger Regions can be viable. Another issue is that during the process fly ash which is considered a hazardous waste is produced. The amount of fly ash equals to around 3% of the incoming waste and has to be landfilled in a hazardous waste landfill. In the Balkan Region still many non-compliant landfills and uncontrolled landfills are still operating and the infrastructure for hazardous waste is scarce. An alternative is to stabilize the fly ash in a cement-solidification plant and deposit the waste in a sanitary landfill for non-hazardous waste or to transfer it abroad in other EU countries. In both cases the operating costs of the facility will significantly increase.

Sanitary Landfills

Landfilling involves the managed disposal of waste on land with little or no pretreatment. Landfilling of biodegradable wastes results in the formation of landfill gas. The methane emitted in landfill gas is thought to represent the main greenhouse gas impact of MSW management. As the least favored option in the waste management hierarchy, landfill should be reserved for stabilized wastes from which no further value may be recovered. Landfill gas may be collected and either disposed of by flaring or used as a fuel. All components of MSW are currently acceptable for landfilling, including residual fractions left over after the separation of materials for recycling and the residues from pre-treatment processes such as incineration and MBT.

Bibliography

BALKWASTE LIFE+ Project (2009). Balkwaste: "Waste Network for sustainable solid waste management planning and promotion of integrated decision tools in the Balkan Region".

Bani, M., Rashid, Z., Hamid, K., Harbawi, M., Alias, A., and Aris, M. (2009). The development of decision support system for waste management; a review. *World Academy of Science, Engineering and Technology*, 49:161.

Briggs, T., Kunsch, P., and Mareschal, B. (1990). Nuclear waste management: An application of the multicriteria PROMETHEE methods. *European Journal of Operational Research*, 44(1):1–10.

Chang, N., Parvathinathan, G., and Breeden, J. (2008). Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region. *Journal of environmental management*, 87(1):139–153.

Chang, N. and Wang, S. (1996). The development of an environmental decision support system for municipal solid waste management. *Computers, environment and urban systems*, 20(3):201–212.

de Oliveira Simonetto, E. and Borenstein, D. (2007). A decision support system for the operational planning of solid waste collection. *Waste Management*, 27(10):1286–1297.

Den Boer, J., Den Boer, E., and Jager, J. (2007). LCA-IWM: a decision support tool for sustainability assessment of waste management systems. *Waste management*, 27(8):1032–1045.

Diakoulaki, D. (2003). *System analysis and decision-making*. National Technical University of Athens.

EUROCONSULTANTS S.A (2010). *Assessment on waste management status in Balkan countries, Greece*. BALKWASTE deliverable 2.

EUROCONSULTANTS S.A (August 2011a). *Guidelines for development of alternative waste management*. BALKWASTE deliverable 4.2.

EUROCONSULTANTS S.A (August 2011b). *Report on the criteria for the assessment of alternative technologies*. BALKWASTE deliverable 4.3.

EUROCONSULTANTS S.A (August 2011c). *Report on the design and implementation of integrated waste management planning*. BALKWASTE deliverable 4.1.

Figueira, J., Greco, S., and Ehrgott, M. (2005). *Multiple criteria decision analysis: state of the art surveys*, volume 78. Springer Verlag.

Gómez-Delgado, M. and Tarantola, S. (2006). Global sensitivity analysis, GIS and multi-criteria evaluation for a sustainable planning of a hazardous waste disposal site in Spain. *International Journal of Geographical Information Science*, 20(4):449–466.

Guerrero, L., Maas, G., and Hogland, W. (2013). Solid waste management challenges for cities in developing countries. *Waste Management*, 33(1):220 – 232.

Haastrup, P., Maniezzo, V., Mattarelli, M., Mazzeo Rinaldi, F., Mendes, I., and Paruccini, M. (1998). A decision support system for urban waste management. *European journal of operational research*, 109(2):330–341.

Hanan, D., Burnley, S., and Cooke, D. (2012). A multi-criteria decision analysis assessment of waste paper management options. *Waste Management*.

Hokkanen, J. and Salminen, P. (1997). Choosing a solid waste management system using multi-criteria decision analysis. *European Journal of Operational Research*, 98(1):19–36.

Kapepula, K., Colson, G., Sabri, K., and Thonart, P. (2007). A multiple criteria analysis for household solid waste management in the urban community of Dakar. *Waste management*, 27(11):1690–1705.

MacDonald, M. (1996). A multi-attribute spatial decision support system for solid waste planning. *Computers, environment and urban systems*, 20(1):1–17.

Panagiotidou, N., Stavrakakis, G., and Venetis, C. (2012a). Sustainable waste management planning with the use of a decision support software tool based on the application of the PROMETHEE II method. In *DSS2012–16th IFIP WG8.3 International Conference on Decision Support Systems, Anavissos, Greece*.

Panagiotidou, N., Stavrakakis, G., Venetis, C., Konstantzos, G., Inglezakis, V., Moustakas, K., and Loizidou, M. (2012b). Decision support software tool for solid waste management planning. In *International Conference on Industrial and Hazardous Waste Crete 2012, Chania, Greece*.

Repoussis, P., Paraskevopoulos, D., Zobolas, G., Tarantilis, C., and Ioannou, G. (2009). A web-based decision support system for waste lube oils collection and recycling. *European Journal of Operational Research*, 195(3):676–700.

Rousis, K., Moustakas, K., Malamis, S., Papadopoulos, A., and Loizidou, M. (2008). Multi-criteria analysis for the determination of the best WEEE management scenario in Cyprus. *Waste Management*, 28(10):1941–1954.

Roussat, N., Dujet, C., and Méhu, J. (2009). Choosing a sustainable demolition waste management strategy using multicriteria decision analysis. *Waste management*, 29(1):12–20.

Saaty, T. (1980). *The Analytic Hierarchy Process*. McGraw-Hill, Inc.

Saaty, T. (1992). *Decision making for leaders*. RWS Publications, Pittsburgh, USA.

Stavrakakis, G., Panagiotidou, N., Moustakas, K., Malamis, D., Loizidou, M., Inglezakis, V., Venetis, C., Dvorsak, S. amd Movila, I., Ardeleanu, N., and L., I. (2010). Development of a decision support software tool for the evaluation of different waste management scenarios. In *ISWA World Congress, Hamburg*.

Tsoutsos, T., Drandaki, M., Frantzeskaki, N., Iosifidis, E., and Kiosses, I. (2009). Sustainable energy planning by using multi-criteria analysis application in the island of Crete. *Energy Policy*, 37(5):1587–1600.

Vego, G., Kucar-Dragicevic, S., and Koprivanac, N. (2008). Application of multi-criteria decision-making on strategic municipal solid waste management in Dalmatia, Croatia. *Waste management*, 28(11):2192–2201.

Ανάπτυξη αναλυτικού υπολογιστικού εργαλείου για την αξιολόγηση εναλλακτικών σχεδίων διαχείρισης αστικών απορριμάτων

Μεταπτυχιακή διατριβή

Παναγιωτίδου Ναταλία

Α.Μ: 2007019016, E-mail: npanagiwtidou@gmail.com

Επιτροπή:

Γ. Σταυρακάκης, Καθηγητής, Τμήμα Ηλεκτρονικών Μηχανικών και Μηχανικών Υπολογιστών, Πολυτεχνείο Κρήτης (Επιβλέπων)

Κ. Καλαιτζάκης, Καθηγητής, Τμήμα Ηλεκτρονικών Μηχανικών και Μηχανικών Υπολογιστών, Πολυτεχνείο Κρήτης

Ε. Γρηγορούδης, Επίκουρος Καθηγητής, Τμήμα Μηχανικών Παραγωγής και Διοίκησης, Πολυτεχνείο Κρήτης

ΤΜΗΜΑ ΗΛΕΚΤΡΟΝΙΚΩΝ ΜΗΧΑΝΙΚΩΝ ΚΑΙ ΜΗΧΑΝΙΚΩΝ ΥΠΟΛΟΓΙΣΤΩΝ
ΠΟΛΥΤΕΧΝΕΙΟ ΚΡΗΤΗΣ

Ανάπτυξη αναλυτικού υπολογιστικού εργαλείου για την αξιολόγηση εναλλακτικών σχεδίων διαχείρισης αστικών απορριμάτων

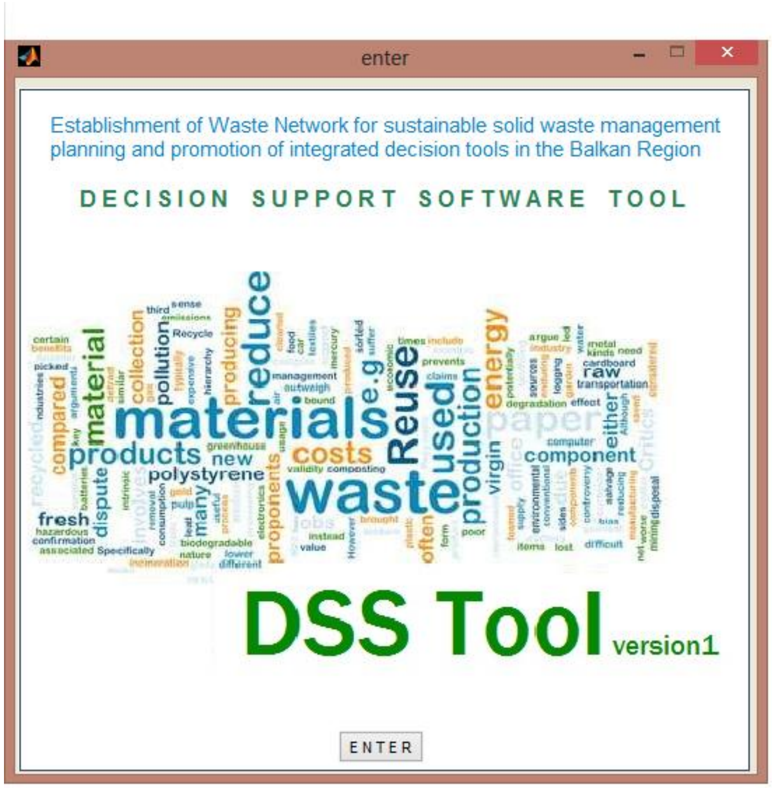
Ένας από τους κύριους στόχους της Ολοκληρωμένης Διαχείρισης Στερεών Απορριμάτων στην Ευρώπη είναι η ενσωμάτωση των περιβαλλοντικών επιπτώσεων στη διαδικασία κατάρτισης ή αναθεώρησης των σχεδίων διαχείρισης αποβλήτων, λαμβάνοντας υπόψη τους οικονομικούς και τεχνολογικούς περιορισμούς. Η πολύπλοκη αλληλεπίδραση μεταξύ αυτών των αντικρουόμενων στόχων εμποδίζει τον προσδιορισμό του βέλτιστου σεναρίου διαχείρισης αποβλήτων για τους δήμους και τις λοιπές αρμόδιες αρχές.

Το γραφικό περιβάλλον με το ενσωματωμένο Σύστημα Υποστήριξης Αποφάσεων (ΣΥΑ) που παρουσιάζεται στην παρούσα εργασία, αναπτύχθηκε για την υποστήριξη λήψης αποφάσεων των εμπλεκόμενων φορέων στη διαχείριση των αποβλήτων στις Βαλκανικές χώρες δεδομένου ενός συνόλου κοινωνικών, τεχνικών, περιβαλλοντικών, οικονομικών και νομοθετικών περιορισμών και ως εκ τούτου, τον προσδιορισμό του πλέον αποτελεσματικού συστήματος διαχείρισης αποβλήτων για την εξεταζόμενη περιοχή (Εικόνα 1).

Σε αυτή την κατεύθυνση, ένα από τα μεγαλύτερα εμπόδια είναι ότι οι περισσότερες από τις Βαλκανικές χώρες δεν έχουν την εμπειρία, τη διαθεσιμότητα των δεδομένων και την υποδομή λόγω της έλλειψης νομοθετικού πλαισίου και εναιαίου σχεδίου δράσης. Έτσι, ήταν σημαντικό η συγκεκριμένη εφαρμογή να είναι σε θέση να ξεπεράσει αυτούς τους περιορισμούς με την ενσωμάτωση προεπιλεγμένων δεδομένων εισόδου ανάλογα με τη χώρα επιλογής, δεδομένα τα οποία προσδιορίστηκαν με βάση την βιβλιογραφία και την εμπειρία στα θέματα διαχείρισης των αποβλήτων σε διάφορες περιοχές των Βαλκανίων. Η παρούσα εργασία περιγράφει τη δομή της εφαρμογής και παρουσιάζει τα αποτελέσματα από τις εφαρμογές του ΣΥΑ στην Ελλάδα, και συγκεκριμένα στις περιοχές της Αττικής και της Κρήτης.

Η δομή του γραφικού περβάλλοντος του ΣΥΑ αποτελείται από τις παρακάτω βασικές ενότητες:

- Αυτόματη διαδικασία εισαγωγής δεδομένων με βάση την επιλογή της χώρας, ποσοτικοποίηση των στόχων που πρέπει να επιτεχθούν για την ανακύκλωση και την εκτροπή των στερεών σποβλήτων απο τους ΧΥΤΑ. Προσδιορισμός της υφιστάμενης κατάστασης και χωρητικότητας των μονάδων διαχείρισης απορριμάτων και την αντίστοιχη ενημέρωση του χρήστη για εφικτές μεθόδους για την περαιτέρω επεξεργασία απορριμάτων.
- Καθοδήγηση του χρήστη για το σχεδιασμό βιώσιμων εναλλακτικών σεναρίων διαχείρισης απορριμάτων με βάση τις διαθέσιμες τεχνολογίες/μεθόδους.
- Ανάλυση ροής υλικών για κάθε επιλεγμένη τεχνολογία και συνολικα για κάθε σενάριο και παρουσίαση αποτελεσμάτων στον χρήστη σχετικά με τα κόστη, τις περιβαλλοντικές επιπτώσεις και τις ποσότητες για τα παραγόμενα προίντα (RDF/SRF, Compost, Ανακυκλώσιμα) και τα υπολείμματα.
- Προσδιορισμός βαρών από το χρήστη/αποφασίζοντα για το σύνολο των κοινωνικό-περιβαλλοντικών, τεχνο-οικονομικών και νομοθετικών κριτηρίων. Εφαρμογή πολυκριτήριας ανάλυσης με την μέθοδο PROMETHEEE II με βάση τις προτημίσεις του χρήστη και παρουσίαση των αντίστοιχων αποτελεσμάτων για την τελική κατάταξη των εναλλακτικών σεναρίων.



Εικόνα 1: Είσοδος στο γραφικό περιβάλλον του ΣΥΑ

Το μοντέλο ποσοτικοποίησης των στόχων ανακύκλωσης και εκτροπής των μικτών αποβλήτων από τους ΧΥΤΑ και η μεθοδολογία για την ανάλυση ροής υλικών ενσωματώθηκαν στο ΣΥΑ με βάση τα παραδοτέα του έργου LIFE+ BALKWASTE.

Για το σκοπό της συγκριτικής ανάλυσης των εναλλακτικών σεναρίων επιλέχθηκαν συνολικά 28 κριτήρια απόφασης, τα οποία ομαδοποιούνται σε περιβαλλοντικά, τεχνικά, οικονομικά, κοινωνικά και νομοθετικά. Η περαιτέρω ομαδοποιησή τους σε ποσοτικά η ποιοτικά γίνεται με βάση τον τρόπο με τον οποίο αξιολογούνται: στην παρούσα εργασία τα ποσοτικά κριτήρια αξιολογούνται με βάση τα αποτελέσματα που προκύπτουν από την ανάλυση ροής υλικών, ενώ τα ποιοτικά κριτήρια αξιολογούνται απευθείας από τον χρήστη με κλίμακα από 0 έως 100 ή μπορούν να χρησιμοποιηθούν προτεινόμενες τιμές, όπως προέκυψαν από τα παραδοτέα του έργου.

Με βάση τις προτιμήσεις των αρμόδιων αρχών για τα βάρη των κριτηρίων απόφασης προσδιορίστικαν μέσες τιμές, οι οποίες αποτελούν το σύνολο των προτεινόμενων βαρών που μπορεί να επιλέξει ο χρήστης μέσω του ΣΥΑ. Σε διαφορετική περίπτωση, δίνεται η δυνατότητα για την εισαγωγή καινούριων βαρών.

Στα πλαίσια του συγκεκριμένου έργου, ως μεθοδολογίες επίλυσης του παραπάνω προβλήματος απόφασης έχει προταθεί να διερευνηθούν μεθοδολογίες πολυκριτήριας ανάλυσης αποφάσεων προερχόμενες από τις οικογένειες ELECTRE (ELimination Et Choix Traduisant la REalité) και PROMETHEE (Preference Ranking Organisation Method for Enrichment Evaluation), καθώς και η AHP (Analytical Hierarchy Process). Απο αυτές τις μεθοδολογίες επιλέχθηκε η PROMETHEE II, η οποία κρίθηκε ως η καταλληλότερη μέθοδος για την επίλυση του συγκεκριμένου πρόβλήματος, καθώς με δεδομένο το πρόβλημα απόφασης που μοντελοποιείται με τα δεδομένα που εισάγει ο χρήστης, η μόνη περαιτέρω απαίτησή θα είναι ο καθορισμός των βαρών των κριτηρίων απόφασης. Η ELECTRE III όπως και η AHP κρίνονται ακατάλληλες λόγω της απαίτησης καθαρισμού κατωφλιών (ELECTRE III) ή χρονοβόρας και πολύπλοκης διαδικασίας συγκρισης και αξιολόγησης κάθε ζεύγους σεναρίων (AHP) από την πλευρά του χρήστη, με αποτέλεσμα να απαιτούνται γνώσεις και εμπειρία που ο χρήστης στον οποίο απευθύνεται το συγκεκριμένο σύστημα, δεν αναμένεται να έχει.

Για την εφαρμογή της PROMETHEE II, πέραν του συνόλου των εναλλακτικών σεναρίων, του συνόλου των κριτηρίων, του Πίνακα Αξιολόγησης που υπολογίζεται αυτόματα από το ΣΥΑ με βάση τα δεδομένα εισόδου από τον χρήστη και των βαρών των κριτηρίων που καθορίζονται από τον χρήστη, ο χρήστης θα πρέπει να επιλέξει για κάθε εξεταζόμενο κριτήριο μια συνάρτηση προτίμησης από τις έξι προτεινόμενες και, ανάλογα με τη συνάρτηση που θα επιλέξει, να ορίσει κατάλληλες τιμές για τις εμπλεκόμενες παραμέτρους.

Όπως έχει αναφερθεί, ο σημαντικός περιορισμός που προκύπτει από την εφαρμογή του ΣΥΑ είναι ότι τα δεδομένα εισόδου διαφέρουν για διαφορετικούς χρήστες, και συνεπώς διαφέρουν και οι επιλογές για τις εναλλακτικές λύσεις, αξιολογήσεις των τεχνολογιών και τα βάρη των κριτηρίων απόφασης. Επιπλέον, καθώς η εφαρμογή του ΣΥΑ απευθύνεται σε μη ειδικούς στον τομέα της διαχείρισης των αποβλήτων και της πολυκριτήριας ανάλυσης, η συμμετοχή του χρήστη στον καθορισμό των συναρτήσεων προτίμησης και κατωφλιών πρέπει να αποφεύγεται. Γι 'αυτούς λόγους επιλέχθηκε μια αυτοματοποιημένη διαδικασία για την εφαρμογή της πολυκριτήριας ανάλυσης σχετικά με την επιλογή της συνάρτησης προτίμησης και αντίστοιχων κατωφλιών. Πιο συγκεκριμένα, για τα ποιοτικά κριτήρια, στα οποία η αξιολόγηση των κριτηρίων γίνεται με βάση την κλίμακα από 0 έως 100, επιλέχθηκε η συνάρτηση προτίμησης *V-shape* με κατώφλι αδιαφορίας. Επίσης το κατώφλι αδιαφορίας και γνήσιας προτίμησης τέθηκαν με 10% και με 25% της κλίμακας αντίστοιχα, ενώ για τα ποσοτικά κριτήρια επιλέχθηκε η συνάρτηση προτίμησης *V-shape* χωρίς το κατώφλι αδιαφορίας. Για τον καθορισμό κατωφλιού γνήσιας προτίμησης, χρησιμοποιήθηκε ο εμπειρικός κανόνας σύμφωνα με τον οποίο για κάθε ποσοτικό κριτήριο το κατώφλι ορίζεται στο 25% της μέγιστης απόκλισης μεταξύ των αξιολογήσεων όλων των σεναρίων στο κριτήριο αυτό.

WASTE TREATMENT TECHNOLOGIES FOR:

BIOWASTE	PACKAGING WASTE	RESIDUAL WASTE:
Capacity (tn): 222,286	Capacity (tn): 0	Capacity (tn): 735,958

	Biowaste	Packaging w...	Technology for Facility1	% for Faciltity1	Technology for facility2	% for Facility2	RDF/SRF treatment
1	Composting	--	MBT-AD-Recyclables	100.00		0.00	Landfilling
2	Composting	--	Biodrying	100.00		0.00	Landfilling
3	Composting	--	Incineration	100.00		0.00	--
4	Composting	--	MBT-Composting-Recyclat	100.00		0.00	Landfilling
5	AD	--	MBT-AD-Recyclables	100.00		0.00	Landfilling
6	AD	--	MBT-Composting-Recyclat	100.00		0.00	Landfilling

Εικόνα 2: Σχεδίαση των εναλλακτικών σεναρίων διαχείρισης απορριμάτων για την περίπτωση της Αττικής

Στη συνέχεια παρουσιάζεται η εφαρμογή του ΣΥΑ για την περίπτωση της Αττικής και της Κρήτης (Εικόνα 2, Εικόνα 3). Τα αποτελέσματα δείχνουν οτι και στις δυο περιπτώσεις ο συνδυασμός της Κομποστοποίησης για το οργανικό υλικό και της Μηχανικής και Βιολογικής επεξεργασίας με την παραγωγή Ανακυκλώσιμων Υλικών για τα μικτά απόβλητα, μπορεί να θεωρηθεί ως «βέλτιστο» σενάριο διαχείρισης απορριμάτων στις εξεταζόμενες περιοχές (Εικόνα 4, Εικόνα 5), δεδομένου οτι επιλέχθηκαν τα προτεινόμενα βάρη για το σύνολο των κριτηρίων του ΣΥΑ. Τα συγκεκριμένα αποτελέσματα επιβεβαιώνουν την υφιστάμενη κατάσταση στην Ελλάδα, καθώς ο συγκεκριμένος συνδυασμός τεχνολογιών εφαρμόζεται με επιτυχία σε αρκετές περιοχές.

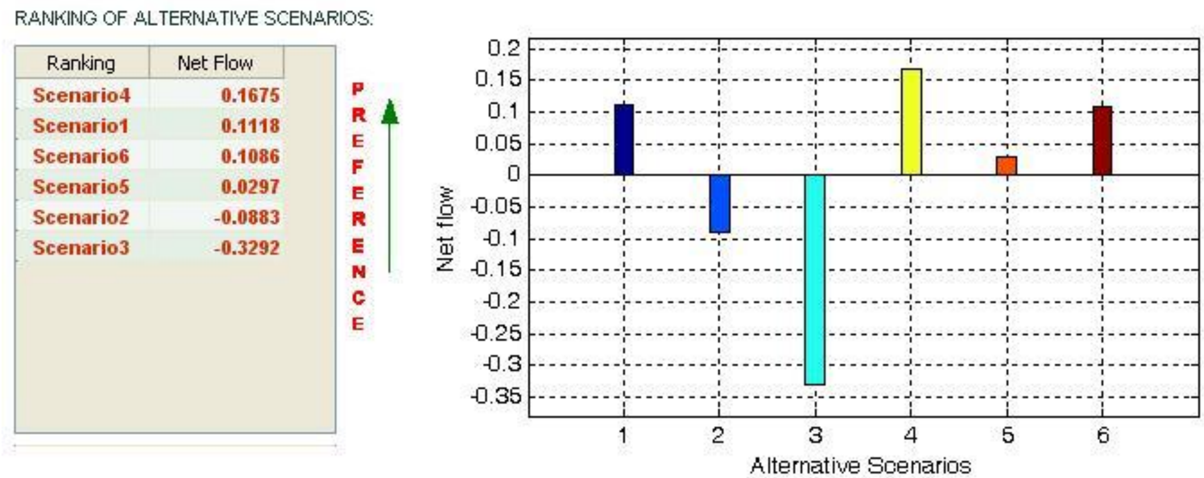
WASTE TREATMENT TECHNOLOGIES FOR:

BIOWASTE	PACKAGING WASTE	RESIDUAL WASTE:
Capacity (tn): 61,497	Capacity (tn): 107,976	Capacity (tn): 75,883

	Biowaste	Packaging w...	Technology for Facility1	% for Faciltity1	Technology for facility2	% for Facility2	RDF/SRF treatment
1	Composting	MRF	MBT-Composting-Recyclat	26.65	Incineration	73.35	--
2	AD	MRF	MBT-Composting-Recyclat	26.65	Incineration	73.35	--
3	Composting	MRF	MBT-Composting-Recyclat	100.00		0.00	Waste to Energy
4	AD	MRF	MBT-Composting-Recyclat	100.00		0.00	Waste to Energy

Εικόνα 3: Σχεδίαση των εναλλακτικών σεναρίων διαχείρισης απορριμάτων για την περίπτωση της Κρήτης

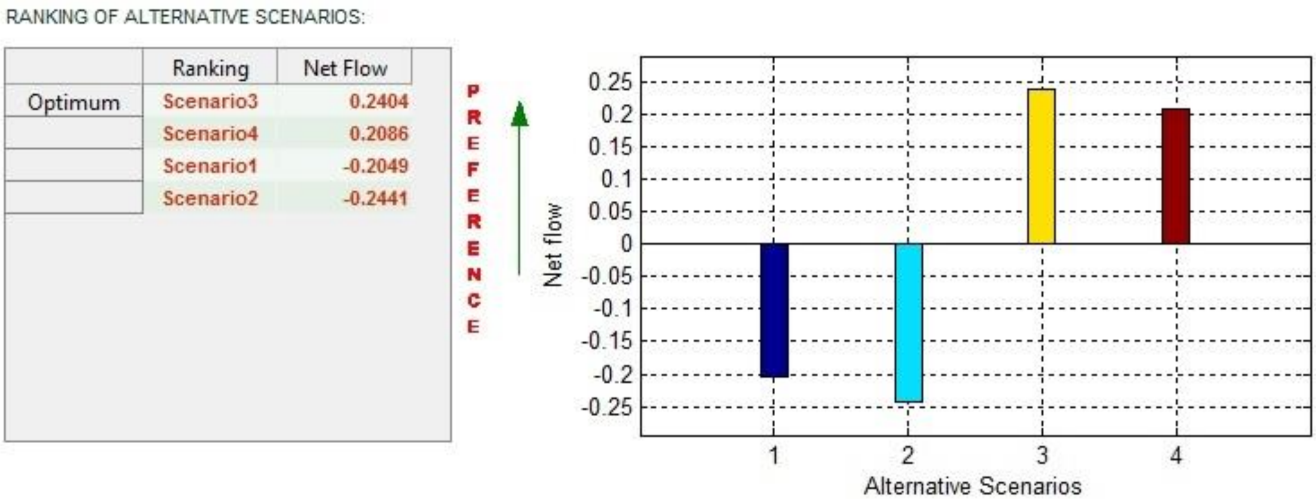
Με σκοπό την διερεύνηση της επίδρασης των βαρών στην τελική κατάταξη των εναλλακτικών σεναρίων, οι αρμόδιες αρχές των τεσσάρων Βαλκανιών χωρών (Βουλγαρία, Ελλάδα, Ρουμανία, Σλοβενία) άλλαξαν τα προτεινόμενα βάρη με βάση τις μεγαλύτερες προτιμήσεις τους είτε ως προς τα κοινωνικο-περιβαλλοντικά είτε οικονομο-τεχνικά κριτήρια. Τα αποτελέσματα από την εφαρμογή των τριών συνόλων βαρών (προτεινόμενα, κοινωνικο-περιβαλλοντικά, τεχνο-οικονομικά) δείχνουν οτι μόνο στην περίπτωση της Κρήτης η κατάταξη των εναλλακτικών σεναρίων αλλάζει για τα οικονομοτεχνικά κριτήρια. Σ’αυτήν περίπτωση τα σενάρια που χρησιμοποιούν την Αναερόβια Χωνεύση για το οργανικό ευνοούνται περισσότερο, με αποτέλεσμα να έχουν καλύτερη κατάταξη.



Εικόνα 4: Τελική κατάταξη των εναλλακτικών σεναρίων για την περιοχή της Αττικής

Επίσης, ιδιαίτερη σημασία δόθηκε στην ανάπτυξη γραφικού περιβάλλοντος για το ΣΥΑ, καθώς η χρήση του απευθύνεται στους μη ειδικούς στα θέματα διαχείρισης απορριμάτων. Για αυτόν τον λόγο ο τρόπος με τον οποίο συμμετέχει ο χρήστης στην διαδικασία σχεδιασμού εναλλακτικών σεναρίων και απόφασης για την βέλτιστη λύση έπρεπε να αυτοματοποιηθεί στο μέγιστο δυνατό. Παρόλ’αυτά, ήταν σημαντικό να δίνεται δυνατότητα στον αποφασίζοντα να ενσωματώσει καινούρια δεδομένα και περιορισμούς, και παράλληλα να εκφράζει τις προτιμήσεις του για την εξεταζόμενη περιοχή.

Τέλος, είναι σημαντικό να τονιστεί, ότι ο στόχος του συγκεκριμένου ΣΥΑ δεν είναι να παρέχει μια βέλτιστη λύση, αλλά να προσφέρει στους αποφασίζοντες μια πλατφόρμα ανταλλαγής γνώσης, εμπερίας και απόψεων σε θέματα που αφορούν την αξιολόγηση και επιλογή των διαφόρων σεναρίων διαχείρισης αποβλήτων.



Εικόνα 5: Τελική κατάταξη των εναλλακτικών σεναρίων για την περιοχή της Κρήτης