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Facility Location for Solid Waste Management through Compilation and Multicriterial Ranking of Optimal Decentralised Scenarios: A Case Study for the Region of Peloponesse in Southern Greece

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المستخلص: هذه الورقة تناقش مشكلة تحديد مواقع مرافق ادارة النفايات الصلبة وبالتحديد ناقشت هذه الورقة واقترحت الخيارات الامثل باختبارها لهذه المرافق من حيث النقل، و التصنيف، والمعالجة، والردم الارضي للمخلفات. تم انشاء قاعدة بيانات كمية وكيفية لمرفق ادارة النفايات الصلبة تحت الدراسة وهي موجودة بجنوب اليونان واستخدمت قاعدة البيانات هذه في النموذج. تم اعادة تعريف نموذج السبكات الخطية ذات الاعداد المختلطة في انشاء النموذج المستخدم في الدراسة. وتم استغلاله لتحديد المعايير المختلفة كل على حده باستخدام هيكل نمذجة تحديد المواقع. ثم تم ترتيب حلول النموذج الناتجة من التعويض عن كل معيار (طريقة المعايير المتعددة ELECTRE III). وفي النهاية تم اختيار افضل سيناريو وعرضه للتطبيق في المواقع المدروسه بحيث يكون موافقا للقوانيين الحالية لادارة النفايات، والنتيجة كانت اقصى فوائد بينية ممكنة ودعم لاعادة التدوير في مجال ادارة النفايات.

المفردات المفتاحية: إدارة النفايات الصلبة، مواقع، مرافق. النموذج الخطي ذو الأعداد المختلطة، طريقة المعايير المتعددة

Abstract: The present paper addresses the problem of locating solid waste management facilities. Specifically, it studies and proposes optimal alternative solutions for the Greek Region of Peloponnese, by examining facilities for transferring, sorting, treating and landfilling of wastes. Quantitative and qualitative databases concerning the current solid waste management at the Region have been created and used by the model. A customized mixed-integer linear network model has been developed and solved for various evaluation criteria on a single-criterion basis by the use of a location-allocation modeling framework. The solutions resulting from the parametrical application of the multicriterial method ELECTRE III are then ranked for the entire criteria-spectrum. The best alternative scenario is presented for the Region in accordance with current legislation on waste management, which maximizes environmental benefits and promotes recycling, in the frame of sustainable waste management.

Keywords: Solid waste management, location, facilities, mixed integer linear model, multicriterial method, ELECTRE III

Notation

A^{M}	Coefficient for calculating the material recovery from waste management facilities	$t \cdot day / t_{waste} \cdot year$
$Ã^{E}$	Energy recovery coefficients concerning corresponding waste management facilities (rotary kiln and RDF facilities)	$MWh \cdot day / t_{waste} \cdot year$
$Å^{Å}_{î}$	Energy recovery coefficients concerning corresponding waste management facilities (landfills)	$MWh \cdot day / t_{waste} \cdot year$
$Ã_{i}^{GHE}$	Emission coefficients for greenhouse effect concerning rotary kiln and RDF facilities	eq. $tco_2 \cdot day / t_{waste} \cdot year$
$Å_{i}^{GHE}$	Emission coefficients fo r greenhouse effect concerning landfills	eq. $tco_2 \cdot day / t_{waste} \cdot year$
ä	Landfill capacity	t_{waste}/day

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ì	Local transfer stations typologies	-
í	Material recovery facilities typologies	-
î	Incineration facilities typologies	-
o	Typologies of landfills	-
ð	Local transfer station system	-
ñ	Material recovery facility	-
ó	Waste-to-energy facility	-
ò	Uncompressed waste flow from local transfer station to the material recovery facility	t_{waste}/day
ô	Landfill	-
$ö^{ì}_{ð}$	Binary variable for locating local transfer stations	0 or 1
$÷^{í}_{ñ}$	Binary variable for locating material recovery facilities	0 or 1
$ø^{î}_{ó}$	Binary variable for locating waste -to-energy facilities	0 or 1
$ù^{ï}_{ô}$	Binary variable for locating landfills	0 or 1
$b^{ð}$	Flow of waste from producer to transfer station ð	t_{waste}/day
c	Flow of waste to material recovery facility	t_{waste}/day
d	Flow of waste to waste -to-energy facility	t_{waste}/day
e	Flow of waste to landfill	t_{waste}/day
f^{v}	Efficiency degree of material recovery facilities	%
$f^{î}$	Efficiency degree of energy recovery facilities	%
g	Upper limit to the capacity of material recovery facilities	t/day
h	Upper limit to the capacity of waste -to-energy facilities	t/day
k	Upper limit to the capacity of local transfer station	t/day
MR_j	Objective function concerning the material recovery from wastes	t/year
$q^{î}$	Residues from waste -to-energy facility	t/day
$s^{í}$	Wastes and residues from material recovery facility	t/day
u	Upper limit to the landfill capacity	t/day

1. Introduction

Environmental protection gained importance in legal, economical and technical terms in Greece (European Parliament and Council, 1994, Joined Ministerial Decision 114218, 1997; Joined Ministerial Decision 69728/824, 1996; Joined Ministerial Decision 113944, 1997). The location of facilities for integrated solid waste treatment and disposal has evolved into a complex issue during the recent years. Furthermore, public acceptance and social opposition are exercising pressure that brings such issues at the top of the political agenda. This trend (in Greece) gradually leads into interesting developments in the field of municipal waste management.

In the late nineties, research focused on implementing the integrated management of municipal waste in various areas in Greece (Karagiannidis and Moussiopoulos, 1997; Karagiannidis, 1998; Perkoulidis et al., 1998). Furthermore, according to the new European legislation (European Parliament and Council, 1994a), several studies were conducted with regard to integrated solid waste management at prefectural level (Karagiannidis et al., 1998; Moussiopoulos et al., 1998; Anatoliki, 1999, Association of Thessaloniki Municipalities, 1999, Perkoulidis et al., 1999; Kouras et al., 2001, Moussiopoulos, 2000; Moussiopoulos et al., 2002).

In order to reduce costs resulting from waste collection and material recovery, fixed and mobile transfer stations are proposed at the Region of Peloponnese, thus discouraging illegal dumping to the over 1,000 existing uncontrolled landfills at this Region (Drossos and Terzopoulos, 1999). It must be pointed out that some material recovery facilities and sanitary landfills are currently in operation at this Region. These facilities should be taken into account during the regional planning for solid waste management, as this is outlined by Greek legislation (Official Journal of the Greek Government, 1999).

2. Background of Modelling Techniques

Various deterministic mathematical programming models have been used for planning solid waste management systems. Linear programming (Hsieh and Ho, 1993; Lund and Tchobanoglous, 1994), mixed integer programming (Anderson, 1968; Fuertes at al., 1974; Gottinger, 1986; Zhu and ReVelle, 1990), dynamic programming (Huang et al., 1992) and multiobjective programming (Perlack and Willis, 1985) are included in these deterministic modelling techniques.

A review of the various methods regarding sitting of facilities related with municipal solid waste management, was presented by Karagiannidis et al., 2002. Anderson and Nigam (1967) examined closely the cost minimisation of waste flows from transfer stations to landfills through the implementation of a branch and bound system. Furthermore, they developed an *in-kilter* algorithm, which disregarded, however, the existence of mass holes (Gottinger, 1988). A mathematical model for selection between alternative solid waste management systems with linear constraints and a non-linear objective function was presented by Helms and Clark (1971). Waste-to-energy facilities and sanitary landfills were considered as candidate facilities by the system. Fixed costs were related to binary variables (0-1), while linear transportation and treatment costs to continuous variables. Helms and Clark considered that residues from waste-to-energy facilities were driven to existing landfill sites.

Marks and Liebman (1970) dealt with the problem of transfer stations location by minimization of the total cost. A brunch and bound system was adopted using the Fulkerson algorithm (1961). Rossman (1971) extended the aforementioned study by adding waste-to-energy facilities in the set of candidate facilities. Esmaili (1972) proposed an optimisation model for minimizing total waste management costs. Gottinger (1998) and Kirca and Erkip (1988) consider the objective function of transportation costs as linear. Erkut and Neuman (1992) created a multi-objective model for locating undesirable facilities through minimization of the total cost. Finally, Caruso et al. (1993) studied the entire range of components that make up the integrated solid waste management system.

The selection of the multicriterial method for the evaluation of solid waste management systems could be characterized as a post-multicriterial problem. Saaty and Alexander (1981) compared candidate areas for locating an undesirable facility through implementation of the Analytic Hierarchy Process (AHP). Vuk and Ko□elj (1991) presented Promethee and Gaia for the selection of a landfill in Slovenia, while Hokkanen and Salminen (1994) implemented ELECTRE III for the selection of a solid waste management system in Finland. Karagiannidis and Moussiopoulos (1997) compared integrated solid waste management systems for the Greater Athens Area, Greece, taking into account 25 criteria with ELECTRE III, which was also used for the same purpose in other Regions in Greece (Perkoulidis, 2001).

3. Objectives

The main objective of the work presented in this paper is the determination of the best location for solid waste management facilities (transfer stations, material recovery facilities, waste-to-energy facilities, landfills), as well as the allocation of wastes (from municipal waste producers and transfer stations) and residues (from treatment facilities). The following steps were followed for the selection of the best alternative solid waste management scenario in the Region of Peloponnese:

- Creation of quantitative and qualitative databases on produced amount of wastes as well as on residues and quantitative analysis respectively per waste producer (municipality). This data was obtained by recording the current status of solid waste management in the Region of Peloponnese.
- Elaboration of the databases with the main characteristics of the existing and candidate solid waste management facilities. These concern mainly the capacity, the investment and operation cost, the amount of recovered energy and the emissions of each facility.
- Definition of linear objective functions through regression analysis. For the determination of these functions, the aforementioned databases (main characteristics of facilities) were used. Each objective function was sequentially adapted to each from a set of criteria; its value was determined as performance.
- Calculation of performances of each criterion. These resulted from the optimisation of the aforementioned objective functions.
- Application of a multicriterial method, in order to evaluate the aforementioned performances.
- Sensitivity analysis in order to derive the frequency distribution of each scenario's ranking from best to worst and lead to the proposal of the best alternative solid waste management scenario.

4. Methodology

The hierarchical facility location system comprises the following four primary levels (European Parliament and Council, 1994; Fishbein and Gelb, 1992 - Figure 1): (Level-a) transfer stations, (Level-b) material recovery facilities, (Level-c) waste-to-energy facilities, and (Level-d) sanitary landfills. A customized mixed-integer linear model is derived in a spreadsheet environment for the studied area by the use of a recent location-allocation, modelling framework (Karagiannidis and Moussiopoulos, 1998; Perkoulidis et al., 1998).

Binary variables set equal to 1 (treated as constants) are the two existing facilities (one landfill in Patra and one material recovery facility in Kalamata), as well as the thirty-six considered transfer stations. The latter is assumed due to the relatively bad rural road network, which makes the use of transfer stations necessary. As waste producers the municipalities at the Region of Peloponnese were considered.

An objective function is sequentially adapted to each criterion from a set of five evaluation criteria used in the present study:

Criterion-1 Greenhouse Effect (GHRE): CO_2 equivalent of CO_2 and CH_4 emitted from facilities operation and residue transportation (kt/year to be minimized - Equation 1, c.f, Figure 1). The values of Γ_ξ^{GHE} and E_o^{GHE} are given in Table 1.

$$\min GHE = \sum_{\xi}\sum_{\sigma}(\Gamma_{\xi}^{GHE} \cdot d_{\sigma}^{\xi}) + \sum\sum(\mathrm{E}_{o}^{GHE} \cdot e_{\tau}^{o}) \quad (1)$$

Typology of existing/proposed facility (i)	Sub-typology of facility (j)	Capacity of facility [ΔE^i_j, (t/d)]	Wastes' input at facility (t/d)	Mass reduction at facility (%)	Residues output from facility (t/d)	Binary decision variables (0, 1)
Transfer station	μ	k	b		t	φ^{μ}_{π}
Material recovery	ν	g	c	f_{MRF}	s	χ^{ν}_{ρ}
Energy recovery	ξ	h	d	f_{WTE}	q	ψ^{ξ}_{σ}
Landfill	o	u	e			ω^{o}_{τ}

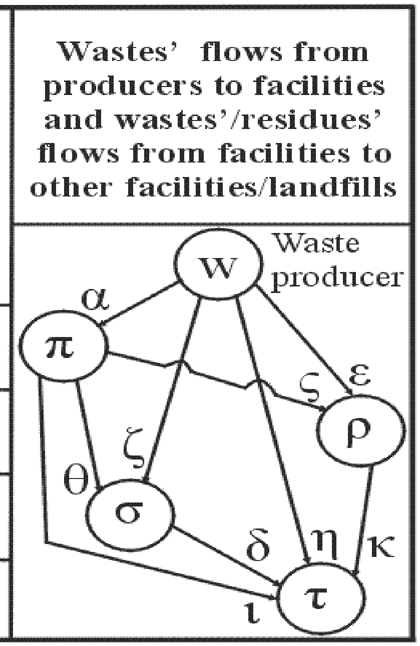

Figure 1. Four primary levels of a hierarchical facility allocation system

(Criterion-2) Final disposal, i.e. the amount of solid wastes from waste producers and transfer stations, as well as the residues from material recovery facilities and waste-to-energy facilities that are finally disposed at sanitary landfills (kt/year to be minimized - Equation 2, cf. Figure 1).

$$\min FIDI = \sum_{o}\sum_{i}\sum_{\tau}\eta^{o}_{i\tau}\cdot\omega^{o}_{\tau} + \sum_{\mu}\sum_{o}\sum_{\pi}\sum_{\tau}\iota^{\mu o}_{\pi\tau}\cdot\omega^{o}_{\tau} + \sum_{\xi}\sum_{o}\sum_{\sigma}\sum_{\tau}\delta^{\xi o}_{\sigma\tau}\cdot\omega^{o}_{\tau} \quad (2)$$

(Criterion-3) Energy recovery i.e., the recovered energy amount from waste-to-energy facilities and sanitary landfills (MWh/year, to be maximized - equation 3, cf. Figure 1, Table 2).

$$\max ER_j = \sum_{\nu}\sum_{\rho}(\mathrm{A}^{E}_{j}\cdot c^{\nu}_{\rho}) + \sum_{\xi}\sum_{\sigma}(\Gamma^{E}_{j}\cdot d^{\xi}_{\sigma}) + \sum_{o}\sum_{\tau}(\mathrm{E}^{E}_{j}\cdot e^{o}_{\tau}) \quad (3)$$

(Criterion-4) Material recovery i.e., the amount of recovered materials from material recovery facilities (kt/year to be maximized - Equation 4, cf. Figure 1, Table 3)

$$\max MR_j = \sum_{\nu}\sum_{\rho}(\mathrm{A}^{M}_{j}\cdot c^{\nu}_{\rho}) + \sum_{\xi}\sum_{\sigma}(\Gamma^{M}_{j}\cdot d^{\xi}_{\sigma}) \quad (4)$$

Criterion-5) total specific financial cost, i.e. facility investment-/operating cost, as well as transportation cost (€/t, to be minimized - Equation 5, Figure 2, Table 4).

Table 1. Emission coefficients for greenhouse effect (equivalent ktco$_2$/year - Kolar, 1990; Baldasano and Cremades 1995; IPTS, 1999).

Emission coefficient	Ã$_i^{GHE}$	Å$_i^{GHE}$
Facility		
Rotary kiln	53,89	
RDF	53,83	
Landfill		12,28

Table 2: Energy recovery coefficients (MWh · day/twaste · year) concerning corresponding waste management facilities (Karagiannidis, 1996).

Facility (j) Coefficient	**RDF**	**Rotary kiln**	**Landfill**
Ã^E_j	96,7	93,6	
Å^A_j			42,7

Table 3: Coefficients for calculating the material recovery from waste management facilities (Karagiannidis, 1996)

Facility (j)	***Coefficient***	**A^M_j**	**Ã^M_j**
Material recovery facility		120,0	
RDF			75,0

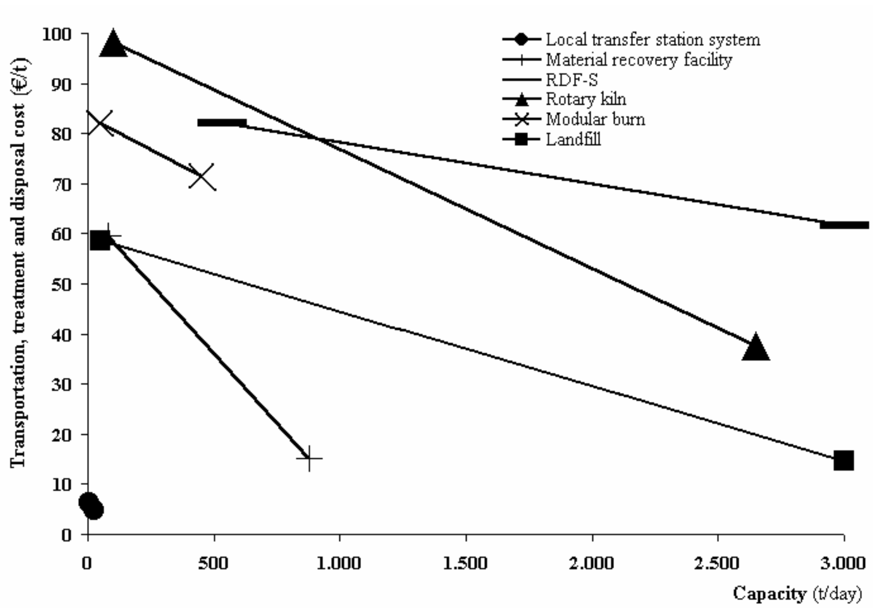

Figure 2. Total cost for the transportation, treatment and final disposal of solid wastes in accordance with facility capacity, (Kamgiannidis, 1996, Perkovlidis, 2001)

$$\begin{aligned}\max FT = &\sum_{\mu}\sum_{\pi}\left[CFF^{\mu}_{\varphi}\cdot\varphi^{\mu}_{\pi} + CFV^{\mu}_{\varphi}\cdot b^{\mu}_{\pi}\right] \\ &+\sum_{\nu}\sum_{\rho}\left[CFF^{\nu}_{\chi}\cdot\chi^{\nu}_{\rho} + CFV^{\nu}_{\chi}\cdot c^{\nu}_{\rho}\right] + \\ &+\sum_{\xi}\sum_{\sigma}\left[CFF^{\xi}_{\psi}\cdot\psi^{\xi}_{\sigma} + CFV^{\xi}_{\sigma}\cdot d^{\xi}_{\sigma}\right] \\ &+\sum_{o}\sum_{\tau}\left[CFF^{o}_{\omega}\cdot\omega^{o}_{\tau} + CFV^{o}_{\omega}\cdot e^{o}_{\tau}\right]\end{aligned} \qquad [5]$$

where τo CFF_i^j represents the fixed cost per each one solid waste management facilities (€ /t) and CFV_i^j represents the variable cost for transport, treatment and final disposal of the wastes (€ / day).

Each solution resulting from the 5 aforementioned linear models are hence called 'scenario'. The constraints of each derived model refer to:

(a) Service demand, i.e. the produced amount of wastes is equal to the sum of capacities from the facilities of the system (Equation 6, cf. Figure 1).

$$\begin{aligned}a_i = &\sum_{\mu}\sum_{\pi}\alpha^{\mu}_{i\pi} + \sum_{\nu}\sum_{\rho}\varepsilon^{\nu}_{i\rho} \\ &+\sum_{\xi}\sum_{\sigma}\zeta^{\xi}_{i\sigma} + \sum_{o}\sum_{\omega}\eta^{o}_{i\omega}\end{aligned} \qquad [6]$$

(b) Facility capacity. This constraint concerns the relationship between the planning capacity of the facility (upper capacity limit in Table 4) and the arriving flows (wastes or residues): b1) $b^{\mu}_{\pi} < \kappa^{\mu}_{\pi}\cdot\varphi^{\mu}_{\pi}$ (local transfer stations), b2) $c^{\nu}_{\rho} < g^{\nu}_{\rho}\,.\,\chi^{\nu}_{\rho}$ (material recovery facilities), b3) $d^{\xi}_{\alpha} < h^{\xi}_{\alpha}\cdot\psi^{\xi}_{\alpha}$ (energy recovery facilities) and b4) $e^{o}_{\tau} < u^{o}_{\tau}\cdot\omega^{o}_{\tau}$ (landfills).

(c) Mass input-output relation at facilities. In case this constraint refers to local transfer stations, then the equation $b^{\mu}_{\pi} = t^{\mu}_{\pi}$ (mass conservation) is in effect. In case of a treatment facility, then the equations $f^{\nu}.c^{\nu}_{\rho} = s^{\nu}_{\rho}$ and $f^{\xi}\,.\,d^{\xi}_{\sigma} = q^{\xi}_{\sigma}$ are in effect for material recovery facilities and WTE facilities, respectively. The f^{ν} and f^{ξ} coefficients are chosen from databases, which resulted from bibliographic data elaboration of material recovery facilities and incinerators (Michos and Pazvanti, 1999; Kampataidis, 1998; and Katsameni and Korakis, 1996).

(d) Compactor- and truck-capacity, maximum allowed gross truck weight and speed limits. Solid wastes were allowed to either leave transfer stations uncompressed (in the case that they are sent to material recovery facilities, by mostly open- containers), or compressed (in the cases they are sent to waste-to energy facilities or landfills).

The location of waste management facilities becomes more complicated due to the resulting necessity for multicriteria evaluation and classification of alternative solutions. In this work, a knowledge base, Figure 3, in combination with a database of solid waste management facilities in Greece (Moussiopoulos et al., 2000) and a relative model generator (Karagiannidis and Moussiopoulos, 1998), was used for the formulation of the location system and the multicriterial analysis of waste flow allocation.

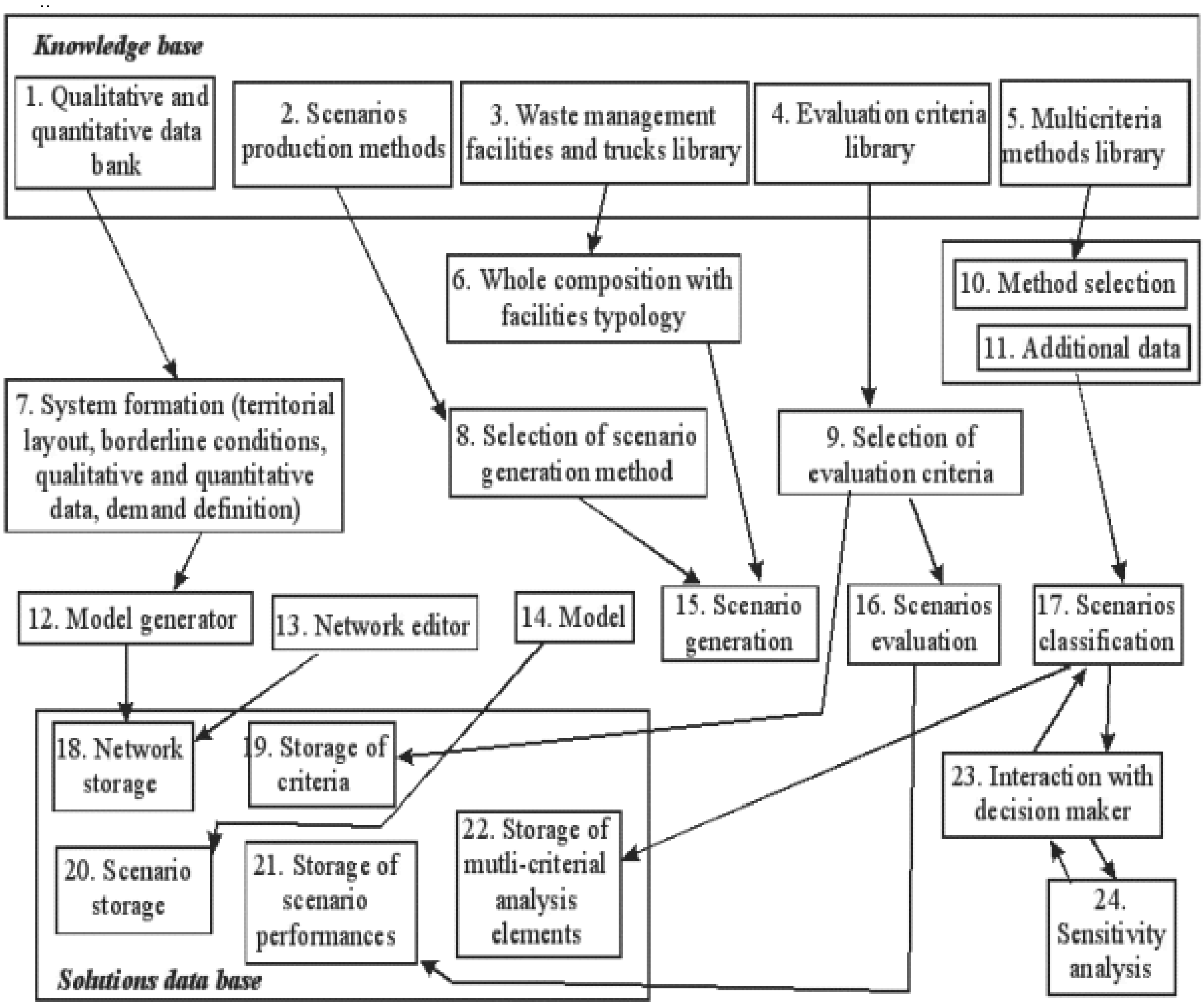

Figure 3. Proposed generic structure of the model-generating framework for integrated waste management models (Karagiannidis, 1996)

5. The Case Study Area

The Region of Peloponnese has a population of 1,171,.000 and lies on the southern edge of mainland Greece, Figure 4. From an administrative point of view, the Region is composed of 7 prefectures: Ilia, Korinthia, Argolis, Achaia, Laconia, Arkadhia and Messinia. The Region is mostly highland, while there are some fertile plains, which mainly stretch along coastal zones. There are intense inter-district inequalities at the Region, due to its separation to industrial and highland zones. Three main road networks lead to places with abundant physical beau-

Table 4. CFF_i^j and CFV_i^j coefficients for calculating the total cost for the transportation, treatment and final disposal of solid wastes (Karagiannidis, 1996, Karagiannidis at al., 1996, Perkovlidis, 2001)

Facility	*Capacity Range (t/d)*	*Investment Cost Range (€/t)*	*Operational Cost Range (€/t)*	*Total Cost Range (€/t)*	CFV_i^j	CFF_i^j
Landfill	50-3,000	-	-	57.00-18.00	-0.01	57.66
Local transfer station	5-25	2.31-0.71	4.11 (const)	6.42-4.82	-0.08	6.82
Material recovery facility	80-880	11.42-7.78	48.06-7.33	59.48-15.11	-0.06	63.92
RDF-S	530-3,000	21.08 (const)	61.10-41.26	82.18-62.34	-0.01	86.44
Rotary kiln	100-2,650	26.66 (const)	71.52-10.99	98.18-37.65	-0.02	100.55

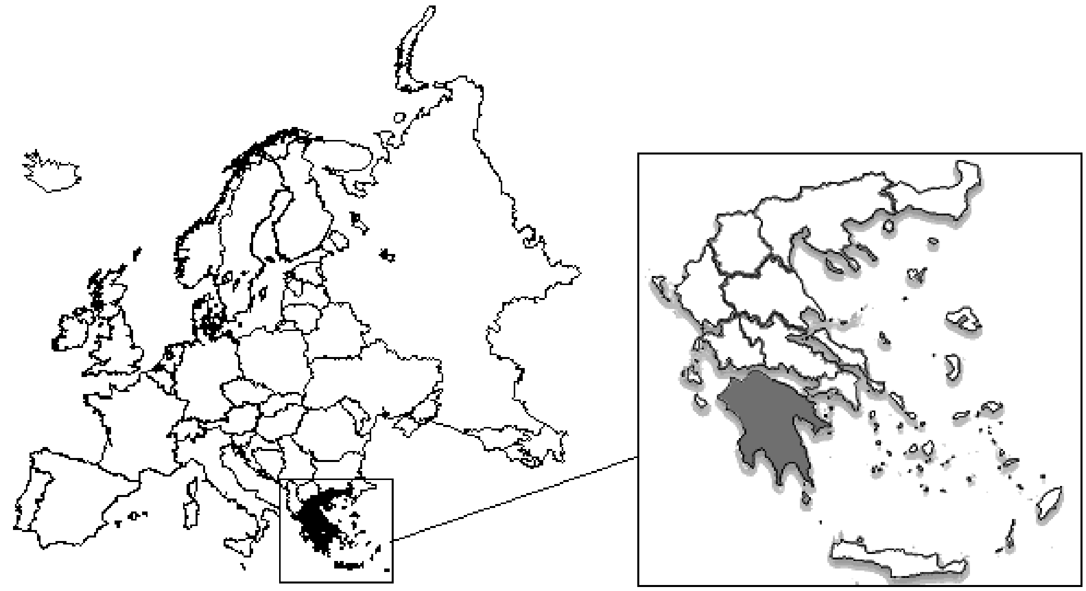

Figure 4. Case-study area (stippled)

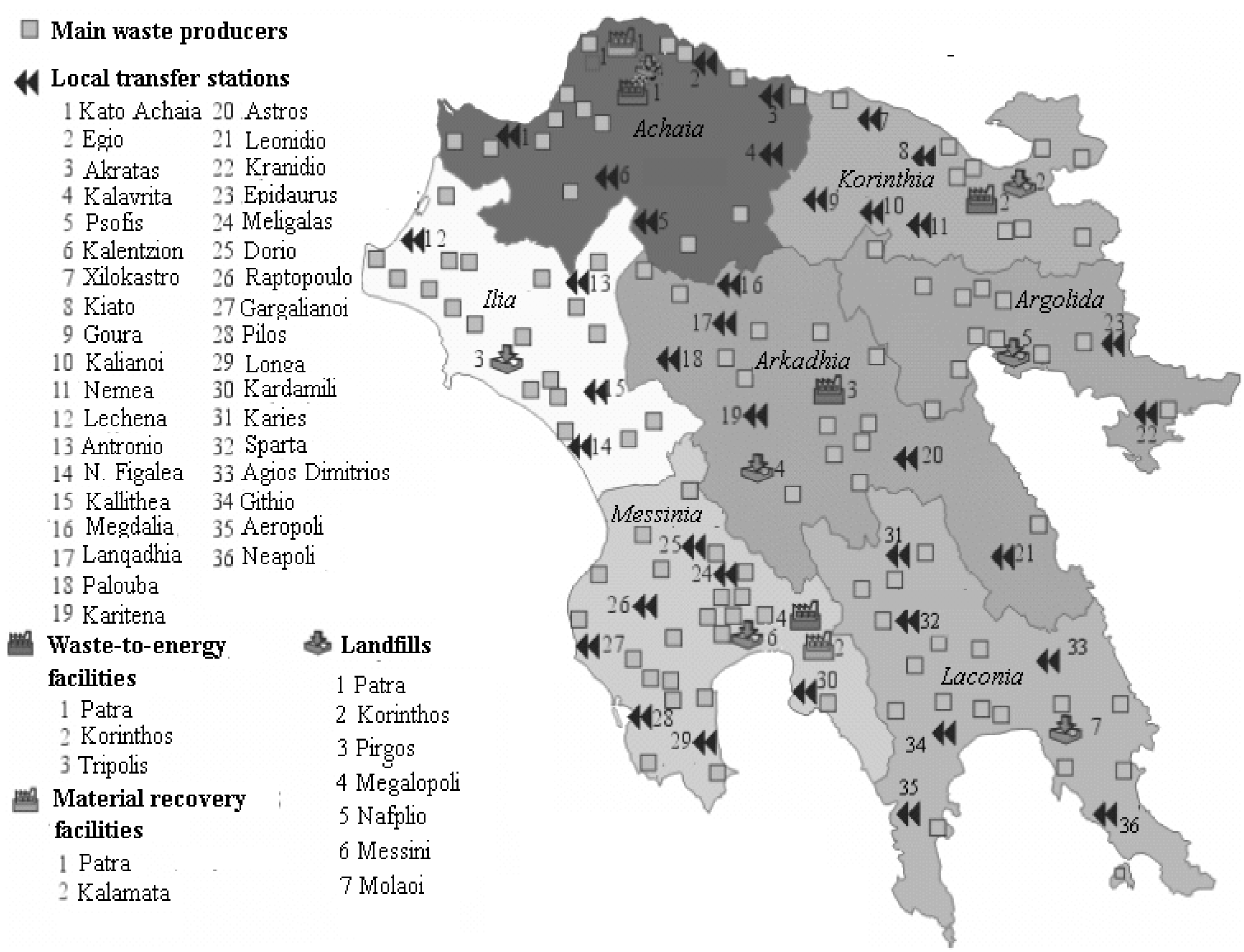

Figure 5. Existing and candidate facilities in case study area

ty and important archaeological sites.

The solid waste collection system in the Region of Peloponnese covers 90% of its population. Here, it should be mentioned that the number of existing uncontrolled landfills is estimated at about 1,000 at the time of the study. The produced amount of wastes is 400,000 t/year. Concerning solid waste management facilities, the Municipality of Patra has proposed the creation of a multi-collecting recycling program, where the construction of one material recovery facility is included. There is also already one sanitary landfill in operation in Patra. Its new cell, with a budget of 2,932,600 €, operates since 1995 and it is estimated that it will cover the needs of Municipality for 15 years. Furthermore, there is one material recovery facility in Kalamata with a total capacity of 400 t/week, which serves the homonymous municipality since 1997. Finally, reported plans concerning the construction of one sanitary landfill in Korinthos, were also taken into consideration, Figure 5.

In this work, the 37 municipalities of the Region of Peloponesse were considered as main waste producers. Related quantitative data is given at Table 5. Due to the dispersion of producers, the transport of produced wastes to distant facilities was proposed to take place by local transfer systems. Finally, it was assumed that energy recovery is performed at all proposed landfills through collection and treatment of the produced biogas, thus also reducing the emitted methane, which contributes significantly to the greenhouse effect (Energy Information Administration, 1999).

The Region of Peloponesse is scheduled to be connected in the near future to the natural gas national network, but at the time the study was conducted it depended solely on the use of lignite for its energy demands. For this reason, the creation of WTE facilities in industrial areas with increased energy demand was proposed (cf. Figure 5). From the application of the model, five decentralized scenarios resulted as alternative solutions concerning the management of solid wastes for each of the five evaluation criteria: 1) minimal impact to the greenhouse effect (scenario 1), 2) minimal amount of landfilled wastes and residues (from the treatment of wastes) to landfills (scenario 2), 3) maximal energy recovery (scenario 3), 4) maximal material recovery (scenario 4) and 5) minimal total cost for the management of produced wastes (scenario 5). Here it should be mentioned that due to the increased dispersion of solid waste management facilities and also due to the emphasis on local management at the period of the study, all five scenarios have a strongly local character (i.e. one landfill per prefecture - Figure 6). The capacities of existing facilities (landfill in Patra and material recovery facility in Kalamata) were set as constant. The results are presented at Table 6.

6. Multicriterial Evaluation of Results

In the following multicriterial approach, all five aforementioned criteria were used. The performances of the five scenarios in all criteria were calculated by means of a pre-compiled knowledge base (Karagiannidis et al., 1996). It must be emphasized that these were quite close to each other in all scenarios (cf. Table 6) due to their decentralized character and the assumption that a great number of facilities existed variable capacity, which was in accordance with the expressed preferences of local decision makers (Drossos and Terzopoulos, 1999). Therefore, apart from the already existing facilities, local authorities of the Region have already expressed their interest for specific candidate facilities (cf. Figure 5).

For global evaluation and ranking purposes, the multi-

Table 5. Produced wastes in the region of Peloponnese

Prefecture	**Number of municipalities**	**Produced wastes** (t/day)	**Prefecture**	**Number of municipalities**	**Produced wastes** (t/day)
Ilia	22	210	Laconia	22	108
Korinthia	15	166	Arkadhia	23	122
Argolis	16	111	Messinia	31	196
Achaia	23	436	**Total**	**152**	**1.349**

Table 6. Performance of the five scenarios

	Greenhouse effect (*equivalent ktco₂/year*)	**Final disposal in landfill (*kt/year*)**	**Energy recovery (*GWh/year*)**	**Material recovery (*kt/year*)**	**Total financial cost *(€/t)***
1	311	388	69	17	87
2	376	356	63	17	86
3	339	389	67	17	87
4	316	387	67	18	87
5	376	358	63	17	86

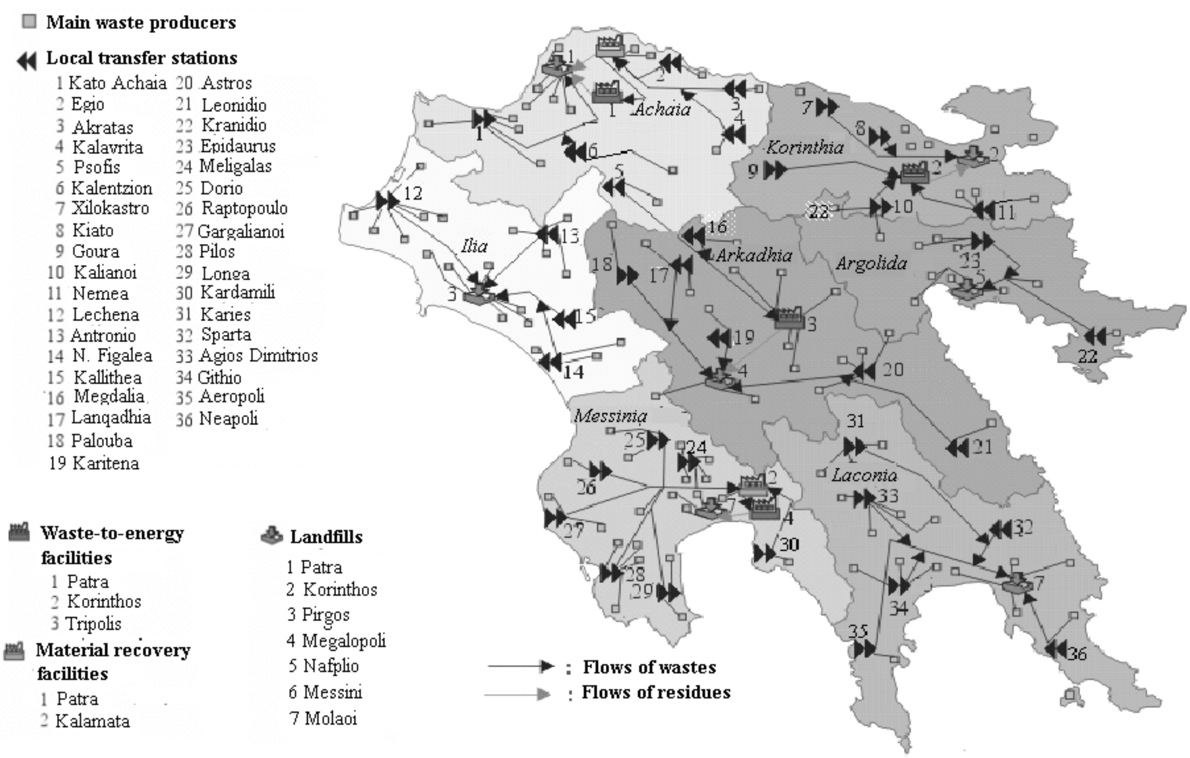

Figure 6. Best alternative solution for location of facilities and allocation of wastes flows

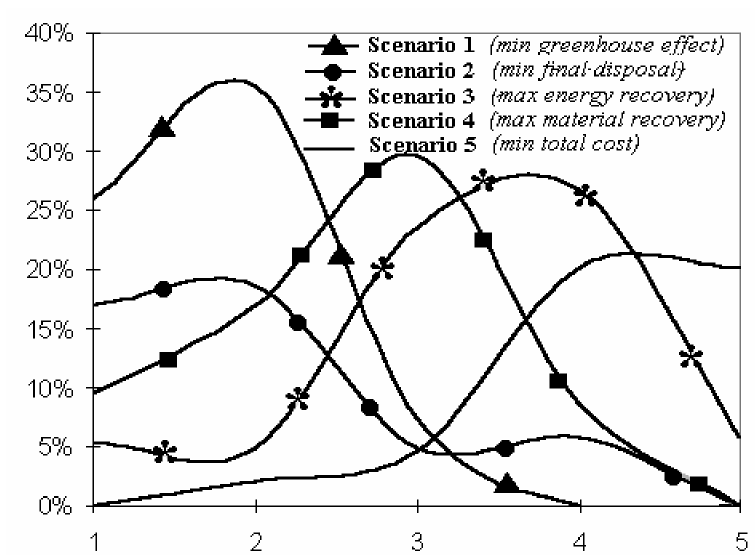

Figure 7. Frequency distribution of each scenario's ranking (position 1: best; position 5: worst) for the 243 considered weight combinations used in sensitivity analysis

criterial approach was chosen. Multi-attribute utility theory, compromising programming, goal programming and discrete methods have been developed as specific multi-criterial techniques. In this context, the well-established ELECTRE III multicriterial method (Rogers and Bruen, 1998a-b; Roy, 1986; 1990) was applied in the present study. A total of 243 independent weight combinations were derived from the sensitivity analysis, which resulted from 50%-step on the 5 criterion-weights (i.e. 0%, 50% and 100%). The frequency distribution of the five positions of each scenario is given in Figure 7.

7. Conclusions and Discussion

Scenario 1 (min of greenhouse effect) was ranked best at 26% (63 cases) in the sensitivity analysis. It was followed by scenario 2 (min final disposal), which appeared at the top 17% of all rankings (cf. Figure 7). Scenario 1 combines recycling and thermal treatment of wastes. Here, it should be mentioned that the same candidate facilities were proposed as existing in all scenarios. Thus, the best alternative scenario also gives the optimal facility capacities (cf. Figure 6). Furthermore, scenario 1 is second-best in terms of cost, following scenarios 2 and 5 (table 6). As far as the second-best position is concerned, scenario 1 (min greenhouse effect) is placed there more frequently than all the others (i.e. 35% of all cases).

The proposed construction of a material recovery facility near the landfill of Patra is in agreement with recent European legislation concerning the diversion of biodegradable wastes from landfills. Furthermore, its existence will facilitate the continuous and steady flow of residue-derived-fuel to the waste-to-energy facility that is proposed to be located close to the city of Patra, an area with high energy demand. Three waste-to-energy facilities are proposed to be located in industrial areas with high energy demand. Finally, seven landfills are proposed in the entire Region, one for each prefecture.

The proposed thirty-six local transfer stations can also be used as drop-off centers for recycling and sending compressed and/or uncompressed wastes to facilities at relatively large distances. They can also contribute to the decommissioning of 'wild' landfills (uncontrolled tipping sites), where the open incineration of wastes causes various forms of pollution. Obviously, their existence reduces the total cost of solid waste management. Furthermore, it should be mentioned that the best alternative solution concerning the proposed construction of a waste-to-energy facility and a material recovery facility in Patra will combine incineration and recycling programs and therefore greatly reduce the volume of landfilled material. By operating effective recycling and collection programs, the prime concerns associated with MSW incineration, i.e. the emissions of heavy metals, acid gases and toxic substances will be minimized (Morrison et al., 1997).

In conclusion, an optimal alternative solid waste management scenario was presented in this paper for a Region in Southern Greece in accordance with current legislation (both Hellenic and European) concerning waste management (Common Ministerial Decision 114218, 1997; Common Ministerial Decision 69728/824, 1996; Common Ministerial Decision 113944, 1997; Directive 369, 1989; Directive 105, 1997). The final placement of facilities and the allocation of wastes and/or residues to them were influenced by: a) the morphological characteristics of the Region, b) the existing road network, c) the physiognomy of grounds (i.e. industrial, agricultural, urban areas) and d) the preferences of local authorities involved in the waste management activities.

Finally, future research should consider a more centralized location of facilities (i.e. one landfill or treatment facility that will be used by at least two prefectures). Thus, inter-prefectural collaborations could also be enhanced in the frame of regional integration of Solid Waste Management.

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